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MATERIALS RESEARCH LABORATORIES

MARIBYRNONG VICTORIA

REPORT 549

FRAGMENTATION DATA ANALYSIS
I. COMPUTER PROGRAM FOR MASS AND NUMBER DISTRIBUTIONS AND EFFECTS OF ERRORS ON MASS DISTRIBUTIONS

P. Krauklis and A. J. Bedford

AUSTRALIAN DEFENCE SCIENTIFIC SERVICE

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ABSTRACT

A computer program is presented which accepts data from a fragmentation test and calculates all the values necessary to plot seven fragment mass and number distribution graphs based on the conventional Mott and Payman Laws.

Errors which can be introduced during the fragmentation experiment are considered in some detail by analysing their possible effects on the fragment mass distributions based on the Payman Law. Trends corresponding to particular error types are characterized and it is concluded that an allowance can be made for errors in many instances. An important finding is that a Payman distribution based on the original cylinder mass is least affected by the errors considered and is thus the method recommended for data analysis.

CONTENTS

FRAGMENTATION DATA ANALYSIS

I. COMPUTER PROGRAM FOR MASS AND NUMBER DISTRIBUTIONS AND EFFECTS OF ERRORS ON MASS DISTRIBUTIONS

1. INTRODUCTION

There is still no known property of a material which can be used to estimate the way it will break up into fragments under the influence of explosive loading. The best method used at present is to carry out simple fragmentation tests, usually on small cylinders in a full recovery pit using water to retard the fragments (1,2). Alternatively, for larger cylinders partial recovery techniques may be used. Upon recovery of the fragments some method is required to obtain fragmentation parameters which can be used to describe the mass or number distributions of the fragments. The two most simple and widely used methods are the Mott and the Payman distribution analyses (3).

It is usually advisable to carry out duplicate or triplicate fragmentation trials and in any series of experiments a large amount of data is accumulated for analysis. There is therefore need in fragmentation experiments to analyse the results rapidly and conveniently.

In the first part of this report a computer program is presented which facilitates the rapid analysis of the mass and number distributions of fragments from raw data. The program is written in Fortran IV language and is used in a PDP10 computer.

Errors can occur in fragment collections which lead to errors in the assessed fragmentation parameters. When fragments are recovered from a fragmentation pit a small proportion may be lost (or gained from previous firings). The rapidity of data analysis using the computer program makes it possible to examine the effects that various errors in the raw fragment data will have on the mass distributions. In the second part of this report therefore, the effects that various errors have on the Payman and Modified Payman (4) fragment distributions are examined in some detail.

In a later report the effects that similar errors have on the Mott distribution analyses will be discussed.

PART 1: ANALYSIS OF FRAGMENT MASS DISTRIBUTION

1. Theoretical Background

The two most commonly used methods of assessing fragment mass distribution are the empirical analysis proposed by Welch and Mott (3,4) and Payman (3,4).

The relationship used in the Welch and Mott analysis in its simplest form may be conveniently expressed as

$$N_m = N_o \exp -\left(\frac{m}{\mu}\right)^{\frac{1}{2}} \tag{1.1}$$

where N_m is the cumulative number of fragments greater than mass m, and N_o and μ are constants. This expression can be rearranged to

$$\text{Log } N_m = \log N_o - \frac{1}{2.303}\left(\frac{m}{\mu}\right)^{\frac{1}{2}} \tag{1.2}$$

It is normal practice to plot log N_m against $m^{\frac{1}{2}}$ to give a straight line relationship. The slope of the line, $-\frac{1}{2.3}\left(\frac{1}{\mu}\right)^{\frac{1}{2}}$, and the intercept, log N_o, are a measure of the fragmentation distribution.

The relationship used in the Payman analysis in its simplest form may be expressed

$$P = K' \exp(-mc') \tag{1.3}$$

where P is the cumulative mass of fragments greater than mass m expressed as a percentage of the total mass M, and K' and c' are constants. The total mass M may be the original cylinder mass (M_O) as proposed originally by Payman (3), or the total mass of recovered fragments (M_R) as suggested by Bedford (4).

This expression can be rearranged to: $\ln P = -c'm + l$, or alternatively

$$\text{Log } P = -cm + K \tag{1.4}$$

where c and K are new constants. Normally log P is plotted against m to give a straight line. The slope of the line, -c, is a measure of the fragmentation.

In some instances (e.g. in experiments where cylinder dimensions are altered) it is more convenient to use plots based on the two relationships described above but which produce a dimensionless fragmentation parameter or slope (4). In these cases the term $\left(\frac{m}{M}\right)^{\frac{1}{2}}$ is plotted on the abscissa for the Mott analysis and the term $\frac{m}{M}$ is plotted on the abscissa for the Payman analysis, making the abscissa and ordinate in both analyses dimensionless. These two variations on the Mott and Payman relationships have been termed the Modified Mott analysis and the Modified Payman analysis respectively.

It is possible to use seven different variations of the two basic relationships described in equations (1.1) and (1.3) depending on whether the normal or modified plot is used and also on whether the original cylinder mass (M_O) or the total mass of recovered fragments (M_R) is used. The variations and the nomenclature adopted in this report are summarised in Table 1.

2. Program FRAMD

The input data consists of an identifying number/name, the cylinder weight and the values of the lower limit of mass range, the total mass and number of fragments occurring in each mass range. All masses are given in grams. The inclusion of the number of fragments is optional; if this information is omitted the program will produce the results for the Payman-based analyses only. An example of an input data file is given in Table 2.

The program calculates the cumulative percentages P_R and P_O and the values of the parameters $\frac{m}{M_O}$, $\frac{m}{M_R}$, $m^{\frac{1}{2}}$, $\left(\frac{m}{M_O}\right)^{\frac{1}{2}}$ and $\left(\frac{m}{M_R}\right)^{\frac{1}{2}}$ corresponding to the value of m defined by each mass range. This information is sufficient to plot the seven different types of graphs listed in Table 1. The output may be obtained in tabulated form and also plotted on the appropriate axes. For example, Table 3 shows the output corresponding to the input data in Table 2, and the corresponding graphs are shown in Figures 1 to 7. A block diagram of the program is shown in Figure 8 and the full program is shown in Figure 9. The terms used in the program are defined in Table 4.

In the program the use of the plotting facility is made optional by means of a pause statement. If the plotting facility is used, then a further option may be exercised, either to apply a standard set of abscissa scaling factors incorporated in the program or to allow the program to select the appropriate scaling factors automatically so as to give a graph with a slope close to unity to facilitate measurement of slope.

It should be noted that the program plots the points of a particular mass distribution only. It does not fit a curve to these points or calculate a slope or intercept. Automatic curve fitting could be expected to be the easiest method of determining these parameters, and indeed, further modification of the program in this direction is anticipated. For the purpose of the work reported in Part 2 however, manual curve fitting allows a degree of flexibility which would be difficult and time-consuming to achieve by automatic methods. This flexibility is important because, as will be pointed out in Part 2, it is possible to recognise certain types of systematic errors in the mass distribution from the shape of the curve and the manual method allows adjustments to be made very easily.

PART 2: THE EFFECTS OF FRAGMENT LOSSES AND MIXING, DURING RECOVERY, ON FRAGMENT DISTRIBUTION CURVES

3. Background

Practical experience with the full water recovery method of collecting fragments used at Materials Research Laboratories for several years has shown that between 75% and 105% of the original cylinder weight is usually recovered as fragments. Most frequently, recoveries are in the range 85% to 100%.

The recovery depends on many factors which may vary from one facility to another, and the task of assessing the effects of these factors on recovery is beyond the scope of this report. However, the following major factors are clearly important in determining recovery:

(a) Design of the fragmentation pit,

(b) Condition of the fragmentation pit,

(c) Position in which the cylinder is fired,

(d) Size of the cylinder,

(e) The methods used to sweep the pit during the recovery process.

These factors can obviously contribute to the failure to recover some of the fragments produced from any particular cylinder, and, in a series of successive firings, can lead to the inclusion of fragments from other cylinders in a particular set of fragments.

If fragments are lost or gained in this way, there is no *a priori* reason to expect that the proportion lost or gained has the same distribution of fragment mass as the true distribution, although a simplifying assumption of this type is usually made in fragmentation experiments for convenience. It is possible, for example, that fine fragments may be lost in a pit with crevices and cracks in the lining. It may also be possible for the mass distribution to be distorted by secondary break-up of fragments.

If the proportion of fragments lost or gained in the fragmentation and recovery processes does not have the same mass distribution as the original set of fragments, then the experimentally measured mass distribution (and hence fragmentation parameter) may be expected to be different from the true value. It is desirable to know the magnitude of the possible effects due to fragment losses or gains of particular kinds during recovery if the fragmentation parameter is to be established with a reasonable degree of accuracy.

Therefore, an evaluation has been made of the effect on fragmentation parameter (i.e., slope of the fragment distribution curve) caused by losses or gains of various amounts of material of different size distributions from idealised fragment distributions using the computer program FRAMD described in Part 1.

The factors which may be varied in examining these types of effects are:

(a) the proportion of fragments lost or gained,

(b) the mass distribution of fragments lost or gained, and

(c) the parameters of the original distribution.

For convenience, work described in this report is confined to distributions of the Payman type; a similar analysis of the Mott distributions will be discussed in a later report. Three idealized distributions of the Payman type are considered; one represents a typical average fragmentation parameter for steel (c_o* = 250) and the others represent the more extreme values of coarse and fine distributions which can be observed in steels (c_o* = 100 and c_o* = 1000 respectively). It should be emphasised that the idealised distributions were chosen to conform as closely as possible to distributions observed in practice (1,2). For each of these three distributions and four different methods of plotting indicated in Table 1, the effect of up to seven different variations in fragment loss or gain was examined as described below. The possibility of identifying and analysing errors arising from fragment losses and mixing is also discussed. In addition, the implications of the present work in relation to partial recovery methods are examined.

4. Calculations

The types of fragment losses and gains considered in this study were:

(a) those in which the fraction lost comprises coarse and fine fragments in the same proportions as the original distribution,

(b) those in which the fraction lost comprises a greater proportion of fine material than the original distribution,

(c) those in which the fraction lost comprises a greater proportion of coarse material than the original distribution, and

(d) any of the above combined with a gain of material having a mass distribution different from that of the material lost and the original distribution.

A cylinder mass of 200 g and idealized Payman 'control' distributions were assumed for each of the three values of c_o* of 250, 100 and 1000. The total mass and number of fragments in each mass group required to produce the 'control' distributions were calculated. The input data were then adjusted by each of the seven hypothetical errors described below, and in each case the four Payman-based plots were recalculated to give the new mass distributions and parameters corresponding to that type of error.

The errors chosen were based on experience of fragmentation testing (See refs. 1,2) and are as follows :

(a) ERROR 1: A loss of 10% of original weight from each weight group.**

(b) ERROR 2: 10% of the cylinder weight lost from the two finest weight groups.

(c) ERROR 3: 5% of the cylinder weight lost from the five coarest groups.**

(d) ERROR 4†: 50% of each of the four coarest weight groups lost, and the same total weight distributed uniformly between the two finest groups.**

(e) ERROR 5†: 10% of the two finest weight groups lost and the same weight gained by the four coarest groups.**

(f) ERROR 6: 30% of the original cylinder weight lost in a sliding scale, mainly from the finer weight groups. The loss from each fraction was in approximate proportion to the total mass of that fraction.**

(g) ERROR 7: One average fragment lost from each group.**

The tabulated control data for one of the idealized distributions ($c_o{}^* = 250$) are shown in Table 3. The tabulated results when ERROR 1 to ERROR 7 are applied to this control data are given in Tables 5 to 11. The Modified Payman-R graphs corresponding to these results are shown in Figs. 10 to 17. Graphs corresponding to the other plots illustrated in Figs.1-4 were also obtained and analysed (a total of 56 graphs). The graphs for the other three Payman-based plots and for $c_o{}^* = 100$ and $c_o{}^* = 1000$ are also not shown individually. However, the results of all calculations performed are summarised in Table 12 and in Figure 18 for the Payman-0 and Payman-R plots and in Figure 19 for the Modified Payman-0 and Modified Payman-R plots. These diagrams show the fragmentation parameters corresponding to the different types of errors at different values of $c_o{}^*$, and the per cent deviation from the control value. The fragmentation parameter was taken as being the slope of the straight line of best fit (judged by eye) in the range $10 < P_O < 100$ and $10 < P_R < 100$. With careful application of this manual curve fitting technique (and after ample practice) it was considered that fragmentation parameters could be determined reproducibly to within 5% from any particular set of data.

5. Discussion of Results

In assessing the results of the calculations the trends which emerge can be seen most readily in Figs. 18 and 19. It is clear from these

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** Adjustments were always made to the coarest weight groups to produce an integral number of fragments. Because of this the resulting percentages were not exactly as stated.

† To represent mixing between successive firings.

diagrams that, although only four of the possible seven error calculations were made for $c_o^* = 100$ and $c_o^* = 1000$, the results for these distributions show the same trends, within experimental error, to the results of calculations for $c_o^* = 250$. Hence, for any particular type of error the percentage deviation from the control value is approximately the same for different values of c_o^*. The small variations in the percentage deviation can be attributed firstly to the fact that the adjustments necessary to produce an integral number of coarse fragments were not always exactly the same and, secondly, to the fact that the straight line of best fit was judged by eye. It is considered that these two factors can adequately account for the small variations in per cent deviation reading across any line of Figs. 18 and 19.

Since the results for $c_o^* = 100$ and $c_o^* = 1000$ do not appear to differ significantly from those for $c_o^* = 250$, [illegible]ese two extreme distributions will not be further discussed a[illegible] the su[illegible]quent discussion applies independently of the value of fragment[illegible]ion pa[illegible]meter.

The discussion is separated int[illegible] [illegible]ection[illegible] [illegible]ealing with the different types of losses in four groups as out[illegible]ed at [illegible] start of Section 4:

(a) <u>The fraction lost contains [illegible] same proportion of coarse and fine material as [illegible]al distribution (ERROR 1)</u>

No significant change in slope is produced by this type of error using the Payman-0, Payman-R and Modified Payman-0 distributions, see Figs. 18 and 19. In the case of the Modified Payman-R plot however, the slope is approximately 10% less than that of the control. This means that each one per cent of material lost causes the slope of the Modified Payman-R graph to be one per cent less than the real value. The opposite effect on slope can be expected if material is gained.

Good recoveries are usually in the range 95-105% (but are frequently as low as 90%) and, if this source of error is not taken into account, an uncertainty of 5-10% could be produced in the slope of the modified Payman-R graph. This problem could be oversome by applying a correction based on the measured recovery and although the correction could be incorporated in the computer program, in practice it is easier to use the Modified Payman-0 plot which is not affected by this type of loss (as is discussed below).

(b) <u>The fraction lost contains a greater proportion of fine material than the original distribution (ERROR 2, ERROR 6)</u>

In the case of the Payman-0, Payman-R and Modified Payman-0 plots Figs. 18 and 19 show that no significant changes are produced by ERROR 2, and small changes are produced by ERROR 6. It should be noted, however, that in the latter case, the total loss of fragments is 30% of the original cylinder weight and for smaller and more realistic losses of fragments the deviation from the real slope could be expected to be much smaller ($\sim$2-3%) therefore negligible. For these three types of plot, therefore, losses (or gains) of this general type do not produce significant effects on the slope of the distribution.

In the case of the Modified Payman-R plot however, an effect of the type noted in (a) above can again be seen in Fig. 19, and the magnitude of the effect is the same as in (a), viz., 1% loss of fragments producing a 1% decrease in the slope from the real value.

(c) The fraction lost contains a greater proportion of coarse material than the original distribution (ERROR 3, ERROR 7)

In the case of the Payman-O, Payman-R and Modified Payman-O distributions a small loss of this type can produce a relatively large increase in the slope and therefore the fragmentation parameter. The deviations away from the original slope shown for these plots in Figs. 18 and 19 represent an increase of 5% in the slope for each 1% of the original cylinder mass lost as coarse fragments, and a decrease of 5% for a 1% gain of coarse fragments.

In the case of the Modified Payman-R plot the same effect can be seen in Fig. 19 except that the magnitude is smaller than for the other three plots, because the effect of material loss described in (a) is superimposed on, and in the opposite sense to, the more pronounced effect caused by loss of coarse fragments.

In all four plots this type of loss or gain shows a characteristic departure from the Payman law. This is shown in Fig. 13 in which 5% gain and 5% loss of the ERROR 3 type is involved. The deviation from the original slope is greatest at high values of m $\left(\text{or } \frac{m}{M_O}, \text{ or } \frac{m}{M_R}\right)$. As the value of m is decreased the deviation decreases even more rapidly so that the new distribution is curved and approaches the original distribution asymptotically as $m \rightarrow 0$, as shown by the broken curves, Fig. 13. The unbroken straight lines in this diagram represent the lines of best fit from which the fragmentation parameter would normally be calculated.

The occurrence of this type of curved departure from the Payman law may be a useful means of identifying this type of error in fragmentation results, particularly if one result from a duplicate or triplicate set of results is suspect because it is substantially different in value.

(d) Material mixing - any of the above types of losses combined with a gain of material in which the size distribution is different

Any case of this type can be considered to be a combination of two or more of the simple effects described in (a) to (c) above.

(i) Coarse Material lost and replaced with the same weight of fine material (ERROR 4)

The basic effect is simular to that described in (c) above with small amounts of mixing causing significant increases in the slope of all four plots. Since it has been established above that losses or gains of finer-than-average material do not produce significant effects, the change in slope in this instance must be due to the loss of coarse fragments. It is interesting to note that the Modified Payman-R plot is not different from the other three plots because there has been no overall loss or gain of material.

(ii) Fine material lost and replaced with the same weight of coarse material (ERROR 5)

The adjustment used here is the reverse of that applied in (i) above and it is not surprising therefore that the effect produced on the slope is also the reverse, with a small amount of mixing producing a significant decrease in the slope of all four plots. Again since the effect of losing fine material can be expected to be negligible, the decrease must be due to the addition of coarse material.

The effects observed for (i) and (ii) above are comparable in magnitude to the 5% change in slope produced by a 1% loss or gain of coarse fragments described in (c) above.

The results indicate that all of the Payman-based plots are sensitive to small losses or gains of coarse fragments. It is not intended in this report to examine in detail which factors in the recovery process can cause preferential loss or gain of coarse fragments. However it is interesting to note that the fortuitous loss of a single large fragment (2 g) from the hypothetical 200 g cylinder can introduce an increase of 5% in the fragmentation parameter. Even with full water recovery the possibility of this type of error cannot be avoided in any particular firing. The only way to reduce the probability of errors from this source is to carry out identical multiple firings.

An alternative to the full water recovery method is a partial water recovery method in which a cylinder is suspended above a water tank and a large steel aperture is used between the cylinder and the tank so that the fragments from a given radial segment of the cylinder are collected. Cylinders of quite large sizes can be fragmented using this technique, and the results can be related to those for a full recovery by multiplying by an appropriate factor. The recoveries experienced with this method are comparable with those produced using a full recovery method, and it is generally accepted that this implies that the results produced by the two methods are comparable in accuracy. It is interesting to note, however, that the fortuitous loss of a single 2 g fragment in the partial recovery case could cause a much greater increase in the slope of the Payman distribution than in the case of full recovery*. Another factor which may

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* The magnitude of this loss can be illustrated with the following example. A 1/12 sample (as obtained from a 30° radial segment) of the control distribution, Table 3, has fractional fragments for $m \geq 1.0$ because there are less than 12 fragments in each of these weight groups. If these fractional fragments are replaced with a single 2 g fragment at $m = 2.0$, the Modified Payman-O parameter of the resulting distribution is 190. If this 2 g fragment is then removed, the same parameter increases to 340. This represents an increase of 150 (or 79%) in the value of the fragmentation parameter, due to the loss of this single fragment.

influence the reliability of partial recovery Payman distributions is a possible unrepresentative sampling effect with coarse fragments. The 5 or 6 coarsest fragments which occur in the largest 2 or 3 mass ranges cannot be spread evenly over, for example, twelve 30° segments, and this must introduce some additional uncertainty in the fragmentation parameter.

CONCLUSIONS

The following conclusions have been reached on the basis of the above analysis of the effect of recovery errors on idealised Payman distributions.

1. All of the mass distributions based on the Payman Law are susceptible to the introduction of error in the slope by the loss or gain during recovery of coarse fragments only. A loss (or gain) of 1% of the original cylinder weight out of the coarsest fragments results in an increase (or decrease) in the slope of the distribution curve by approximately 5%. This type of discrepancy can be diagnosed by the characteristic curvature it produces in the original straight line Payman distribution, particularly if duplicate or triplicate results are available.

2. The Payman plot and the Modified Payman plot based on M_O are not significantly affected by the other types of material loss or gain considered. The loss of up to 10% of the original cylinder weight from the finer weight groups or uniformly from all weight groups does not affect the slope of these plots significantly.

3. The slope of the Modified Payman distribution based on recovered weight M_R is affected by the loss or gain of material independently of the mass distribution of the material lost or gained. A useful approximation for practical purposes is that a 1% loss (or gain) of the original cylinder mass results in about a 1% decrease (or increase) in the slope of the distribution curve from the true value. This effect can be compensated with a simple correction based on the measured recovery, but in practice it is much easier to use the Modified Payman plot based on the original cylinder mass instead of that based on the recovered mass.

4. If the losses or gains noted in 1 to 3 above occur simultaneously, the resultant effect is simply the sum of individual effects.

5. The conclusions above apply irrespective of the value of the fragmentation parameter in the range $100 < c_o{}^* < 1000$.

6. If the Payman analysis is applied to the results of partial recovery experiments, care should be taken in interpreting results because the effects of losing coarse fragments may be more pronounced than with the full recovery method.

RECOMMENDATIONS

On the basis of the above conclusions it is recommended that :

(a) The Payman and modified Payman distributions based on original cylinder mass should be used in preference to distributions based on recovered mass.

(b) Full recovery of fragments should be used in preference to partial recovery where this is experimentally possible.

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TABLE 1

DEFINITIONS OF TERMS AND NOMENCLATURE USED IN VARIOUS TYPES OF PLOTS

		Ordinate	Abscissa	
1	Payman-0	Log P_O	m (g)	$- c_O \ (g^{-1})$
2	Payman-R	Log P_R	m (g)	$- c_R \ (g^{-1})$
3	Modified Payman-0	Log P_O	$\frac{m}{M_O}$	$- c_O^*$
4	Modified Payman-R	Log P_R	$\frac{m}{M_R}$	$- c_R^*$
5	Mott	Log N	$m^{\frac{1}{2}} \ (g^{\frac{1}{2}})$	$- \frac{1}{2.3} \left(\frac{1}{\mu}\right)^{\frac{1}{2}} \ (g^{-\frac{1}{2}})$
6	Modified Mott-0	Log N	$\left(\frac{m}{M_O}\right)^{\frac{1}{2}}$	$- \frac{1}{2.3} \left(\frac{1}{\mu_O}\right)^{\frac{1}{2}}$
7	Modified Mott-R	Log N	$\left(\frac{m}{M_R}\right)^{\frac{1}{2}}$	$- \frac{1}{2.3} \left(\frac{1}{\mu_R}\right)^{\frac{1}{2}}$

* 0 denotes a plot based on original cylinder weight and
R denotes a plot based on the total weight of recovered fragments.

** The negative sign is often omitted for convenience and the parameter is expressed as a positive real number. The following relationships apply between the terms defined in this column.

$$c_O = \frac{c_O^*}{M_O} \qquad (1.5)$$

$$c_R = \frac{c_R^*}{M_R} \qquad (1.6)$$

$$\mu = M_O \mu_O = M_R \mu_R \qquad (1.7)$$

TABLE 2

TYPICAL INPUT DATA FILE (FRAG) FOR THE PROGRAM FRAMD

CONTROL[A]

200.0[B]

0.0[C]	52.0[D]	1100.[E]
0.1	36.0	250.
0.2	50.0	170.
0.4	27.0	52.
0.6	15.4	23.
0.8	8.4	9.
1.0	5.0	5.
1.2	2.6	2.
1.4	1.6	1.
1.6	2.0	1.

-1.[F]

A. cylinder number (2A5)

B. cylinder weight (F6.0)

C. lower limit of mass range (F6.0)

D. Weight in mass range (F6.0)

E. Number in mass range (F6.0)

F. negative number to terminate data file.

TABLE 3
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # CONTROL
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	52.0	1100	200.0	1613	100.0	100.0	0.00	0.0	0.0	0.00	0.00
0.10	36.0	250	148.0	513	74.0	74.0	0.32	5.0	5.0	2.24	2.24
0.20	50.0	170	112.0	263	56.0	56.0	0.45	10.0	10.0	3.16	3.16
0.40	27.0	52	62.0	93	31.0	31.0	0.63	20.0	20.0	4.47	4.47
0.60	15.4	23	35.0	41	17.5	17.5	0.77	30.0	30.0	5.48	5.48
0.80	8.4	9	19.6	18	9.8	9.8	0.89	40.0	40.0	6.32	6.32
1.00	5.0	5	11.2	9	5.6	5.6	1.00	50.0	50.0	7.07	7.07
1.20	2.6	2	6.2	4	3.1	3.1	1.10	60.0	60.0	7.75	7.75
1.40	1.6	1	3.6	2	1.8	1.8	1.18	70.0	70.0	8.37	8.37
1.60	2.0	1	2.0	1	1.0	1.0	1.26	80.0	80.0	8.94	8.94

TABLE 4

DEFINITION OF TERMS IN COMPUTER PROGRAM - FRAMD

CYL, NO = Cylinder number

CYLW = Cylinder mass (grams)

WAG = Bottom value of mass range into which fragments are sorted. (i.e. it is the value of m in the Mott and Payman equations). (= MASS in table).

WT = Mass of fragments in a given mass range. (= WT in Table).

FN = Number of fragments in mass grouping. (= NO. in table).

FNC = Cumulative number of fragments. (= CUM NO. in table).

WC = Cumulative mass of fragments. (= CUM WT in table).

FMS = $m^{\frac{1}{2}}$ (= $\sqrt{\text{WAG}}$) - for Mott Equation. (= SQRT MASS in table).

FNW = $\frac{m}{M_R}$

FOW = $\frac{m}{M_R} \times 10^4$

(= M/MR * 1E4, in table).

SNW = $\left(\frac{m}{M_R}\right)^{\frac{1}{2}}$

SOW = $\left(\frac{m}{M_R} \times 10^4\right)^{\frac{1}{2}}$ (= SQRT M/MR * 1E2 in table).

FNM = $\frac{m}{M_O}$

FOM = $\frac{m}{M_O} \times 10^4$ (= M/MO * 1E4 in table)

SNM = $\left(\frac{m}{M_O}\right)^{\frac{1}{2}}$

SOM = $\left(\frac{m}{M_O} \times 10^4\right)^{\frac{1}{2}}$ (= SQRT M/MO * 1E2 in table).

PR $= \frac{\text{CUM WT}}{M_R} \times 10^2 = \left(\frac{WC}{M_R} \times 10^2\right)$ = Cumulative mass as a percentage of total recovered mass.

(= PR in table).

PO $= \frac{\text{CUM WT}}{M_o} \times 10^2 = \left(\frac{WC}{M_o} \times 10^2\right)$ = Cumulative mass as a percentage of original cylinder weight.

<u>Variables used for plotting graphs</u>

A $=$ WAG $= m$

B $= LOG_{10}PO$

C $= LOG_{10}PR$

D $=$ FNM $= \frac{m}{M_o}$

F $=$ FNW $= \frac{m}{M_R}$

H $=$ FMS $= \sqrt{WAG} = m^{\frac{1}{2}}$

P $= LOG_{10}FNC = LOG_{10}Nm$

R $=$ SNW $= \left(\frac{m}{M_R}\right)^{\frac{1}{2}}$

S $=$ SNM $= \left(\frac{m}{M_o}\right)^{\frac{1}{2}}$

TABLE 5
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # ERROR 1
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	46.8	1200	180.0	1657	100.0	90.0	0.00	0.0	0.0	0.00	0.00
0.10	32.4	220	133.2	457	74.0	66.6	0.32	5.6	5.0	2.36	2.24
0.20	45.0	150	100.8	237	56.0	50.4	0.45	11.1	10.0	3.33	3.16
0.40	24.3	50	55.8	87	31.0	27.9	0.63	22.2	20.0	4.71	4.47
0.60	13.9	20	31.5	37	17.5	15.7	0.77	33.3	30.0	5.77	5.48
0.80	7.6	9	17.6	17	9.8	8.8	0.89	44.4	40.0	6.67	6.32
1.00	4.5	4	10.0	8	5.6	5.0	1.00	55.6	50.0	7.45	7.07
1.20	2.3	2	5.5	4	3.1	2.8	1.10	66.7	60.0	8.16	7.75
1.40	1.4	1	3.2	2	1.8	1.6	1.18	77.8	70.0	8.82	8.37
1.60	1.8	1	1.8	1	1.0	0.9	1.26	88.9	80.0	9.43	8.94

TABLE 6
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # ERROR 2
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	42.0	1000	180.0	1440	100.0	90.0	0.00	0.0	0.0	0.00	0.00
0.10	26.0	175	138.0	440	76.7	69.0	0.32	5.6	5.0	2.36	2.24
0.20	50.0	170	112.0	265	62.2	56.0	0.45	11.1	10.0	3.33	3.16
0.40	27.0	55	62.0	95	34.4	31.0	0.63	22.2	20.0	4.71	4.47
0.60	15.4	22	35.0	40	19.4	17.5	0.77	33.3	30.0	5.77	5.48
0.80	8.4	9	19.6	18	10.9	9.8	0.89	44.4	40.0	6.67	6.32
1.00	5.0	5	11.2	9	6.2	5.6	1.00	55.6	50.0	7.45	7.07
1.20	2.6	2	6.2	4	3.4	3.1	1.10	66.7	60.0	8.16	7.75
1.40	1.6	1	3.6	2	2.0	1.8	1.18	77.8	70.0	8.82	8.37
1.60	2.0	1	2.0	1	1.1	1.0	1.26	88.9	80.0	9.43	8.94

TABLE 7
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # ERROR 3
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	52.0	1100	188.4	1594	100.0	94.2	0.00	0.0	0.0	0.00	0.00
0.10	36.0	240	136.4	494	72.4	68.2	0.32	5.3	5.0	2.30	2.24
0.20	50.0	170	100.4	254	53.3	50.2	0.45	10.6	10.0	3.26	3.16
0.40	27.0	54	50.4	84	26.8	25.2	0.63	21.2	20.0	4.61	4.47
0.60	15.4	22	23.4	30	12.4	11.7	0.77	31.8	30.0	5.64	5.48
0.80	4.7	5	8.0	8	4.2	4.0	0.89	42.5	40.0	6.52	6.32
1.00	2.0	2	3.3	3	1.8	1.7	1.00	53.1	50.0	7.29	7.07
1.20	1.3	1	1.3	1	0.7	0.6	1.10	63.7	60.0	7.98	7.75
1.40	0.0	0	0.0	0	0.0	0.0	1.18	74.3	70.0	8.62	8.37
1.60	0.0	0	0.0	0	0.0	0.0	1.26	84.9	80.0	9.22	8.94

TABLE 7 (CONT.)
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # -ERROR 3
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	52.0	1100	211.6	1623	100.0	105.8	0.00	0.0	0.0	0.00	0.00
0.10	36.0	250	159.6	523	75.4	79.8	0.32	4.7	5.0	2.17	2.24
0.20	50.0	170	123.6	273	58.4	61.8	0.45	9.5	10.0	3.07	3.16
0.40	27.0	52	73.6	103	34.8	36.8	0.63	18.9	20.0	4.35	4.47
0.60	15.4	23	46.6	51	22.0	23.3	0.77	28.4	30.0	5.32	5.48
0.80	12.1	13	31.2	28	14.7	15.6	0.89	37.8	40.0	6.15	6.32
1.00	8.0	8	19.1	15	9.0	9.6	1.00	47.3	50.0	6.87	7.07
1.20	3.9	3	11.1	7	5.2	5.5	1.10	56.7	60.0	7.53	7.75
1.40	3.2	2	7.2	4	3.4	3.6	1.18	66.2	70.0	8.13	8.37
1.60	4.0	2	4.0	2	1.9	2.0	1.26	75.6	80.0	8.70	8.94

CYLINDER # ERROR 4
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	55.8	1300	199.9	1828	100.0	99.9	0.00	0.0	0.0	0.00	0.00
0.10	39.6	270	144.1	528	72.1	72.0	0.32	5.0	5.0	2.24	2.24
0.20	50.0	170	104.5	258	52.3	52.2	0.45	10.0	10.0	3.16	3.16
0.40	27.0	54	54.5	88	27.3	27.2	0.63	20.0	20.0	4.47	4.47
0.60	15.4	22	27.5	34	13.8	13.7	0.77	30.0	30.0	5.48	5.48
0.80	8.4	9	12.1	12	6.1	6.0	0.89	40.0	40.0	6.33	6.32
1.00	2.4	2	3.7	3	1.9	1.8	1.00	50.0	50.0	7.07	7.07
1.20	1.3	1	1.3	1	0.7	0.6	1.10	60.0	60.0	7.75	7.75
1.40	0.0	0	0.0	0	0.0	0.0	1.18	70.0	70.0	8.37	8.37
1.60	0.0	0	0.0	0	0.0	0.0	1.26	80.0	80.0	8.95	8.94

TABLE 9 FRAGMENT MASS DISTRIBUTION
****

CYLINDER # ERROR 5
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	46.8	950	200.0	1441	100.0	100.0	0.00	0.0	0.0	0.00	0.00
0.10	32.4	220	153.2	491	76.6	76.6	0.32	5.0	5.0	2.24	2.24
0.20	50.0	170	120.8	271	60.4	60.4	0.45	10.0	10.0	3.16	3.16
0.40	27.0	54	70.8	101	35.4	35.4	0.63	20.0	20.0	4.47	4.47
0.60	15.4	22	43.8	47	21.9	21.9	0.77	30.0	30.0	5.48	5.48
0.80	8.4	9	28.4	25	14.2	14.2	0.89	40.0	40.0	6.32	6.32
1.00	7.2	7	20.0	16	10.0	10.0	1.00	50.0	50.0	7.07	7.07
1.20	4.8	4	12.8	9	6.4	6.4	1.10	60.0	60.0	7.75	7.75
1.40	3.1	2	8.0	5	4.0	4.0	1.18	70.0	70.0	8.37	8.37
1.60	4.9	3	4.9	3	2.4	2.4	1.26	80.0	80.0	8.94	8.94

TABLE 10
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # ERROR 6
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	34.0	700	139.0	1042	100.0	69.5	0.00	0.0	0.0	0.00	0.00
0.10	21.0	140	105.0	342	75.5	52.5	0.32	7.2	5.0	2.68	2.24
0.20	38.0	130	84.0	202	60.4	42.0	0.45	14.4	10.0	3.79	3.16
0.40	21.0	42	46.0	72	33.1	23.0	0.63	28.8	20.0	5.36	4.47
0.60	12.4	18	25.0	30	18.0	12.5	0.77	43.2	30.0	6.57	5.48
0.80	6.6	7	12.6	12	9.1	6.3	0.89	57.6	40.0	7.59	6.32
1.00	3.2	3	6.0	5	4.3	3.0	1.00	71.9	50.0	8.48	7.07
1.20	1.4	1	2.8	2	2.0	1.4	1.10	86.3	60.0	9.29	7.75
1.40	1.4	1	1.4	1	1.0	0.7	1.18	100.7	70.0	10.04	8.37
1.60	0.0	0	0.0	0	0.0	0.0	1.26	115.1	80.0	10.73	8.94

TABLE 11
****

FRAGMENT MASS DISTRIBUTION

CYLINDER # ERROR 7
CYLINDER WT 200.0

MASS	WT	NO	CUMWT	CUMNO	PR	PO	SQRT MASS	M/MR *1E4	M/MO *1E4	SQRT M/MR *1E2	SQRT M/MO *1E2
0.00	51.9	1100	191.4	1592	100.0	95.7	0.00	0.0	0.0	0.00	0.00
0.10	35.8	240	139.5	492	72.9	69.8	0.32	5.2	5.0	2.29	2.24
0.20	49.7	165	103.7	252	54.2	51.8	0.45	10.4	10.0	3.23	3.16
0.40	26.5	53	54.0	87	28.2	27.0	0.63	20.9	20.0	4.57	4.47
0.60	14.7	21	27.5	34	14.4	13.7	0.77	31.3	30.0	5.60	5.48
0.80	7.5	8	12.8	13	6.7	6.4	0.89	41.8	40.0	6.47	6.32
1.00	4.0	4	5.3	5	2.8	2.7	1.00	52.2	50.0	7.23	7.07
1.20	1.3	1	1.3	1	0.7	0.6	1.10	62.7	60.0	7.92	7.75
1.40	0.0	0	0.0	0	0.0	0.0	1.18	73.1	70.0	8.55	8.37
1.60	0.0	0	0.0	0	0.0	0.0	1.26	83.6	80.0	9.14	8.94

TABLE 12

EFFECT OF ERRORS 1 TO 7 ON FRAGMENTATION PARAMETERS

Error# and Distribution	FRAGMENTATION PARAMETER (and Per cent Deviation from Control Value)					
	Payman Control Value c_O or c_R	Payman-O c_O	Payman-R c_R	Modified Payman Control Value c_O^* or c_R^*	Modified Payman-O c_O^*	Modified Payman-R c_R^*
ERROR 1						
Coarse	-	-	-	-	-	-
Medium	1.25	1.26(+1)	1.26(+1)	250	251(0)	226(-10)
Fine	-	-	-	-	-	-
ERROR 2						
Coarse	0.50	0.50(0)	0.50(0)	100	100(0)	89(-11)
Medium	1.25	1.24(-1)	1.24(-1)	250	246(-2)	225(-10)
Fine	5.0	5.0 (0)	5.0 (0)	1000	994(-1)	905(-10)
ERROR 3						
Coarse	0.50	0.62(+24)	0.62(+24)	100	129(+29)	108(+8)
Medium	1.25	1.55(+24)	1.58(+26)	250	302(+21)	286(+14)
Fine	5.0	6.4 (+28)	6.4 (+28)	1000	1286(+29)	1203(+20)
ERROR 4						
Coarse	-	-	-	-	-	-
Medium	1.25	1.46(+17)	1.45(+16)	250	295(+18)	292(+17)
Fine	-	-	-	-	-	-
ERROR 5						
Coarse	-	-	-	-	-	-
Medium	1.25	1.01(-19)	1.01(-19)	250	203(-19)	202(-19)
Fine	-	-	-	-	-	-
ERROR 6						
Coarse	0.50	0.53(+6)	0.54(+8)	100	107(+7)	72(-28)
Medium	1.25	1.30(+4)	1.29(+3)	250	263(+5)	188(-25)
Fine	5.0	5.6(+12)	5.5(+10)	1000	1106(+11)	775(-23)
ERROR 7						
Coarse	-	-	-	-	-	-
Medium	1.25	1.47(+18)	1.50(+20)	250	283(+13)	267(+7)
Fine	-	-	-	-	-	-

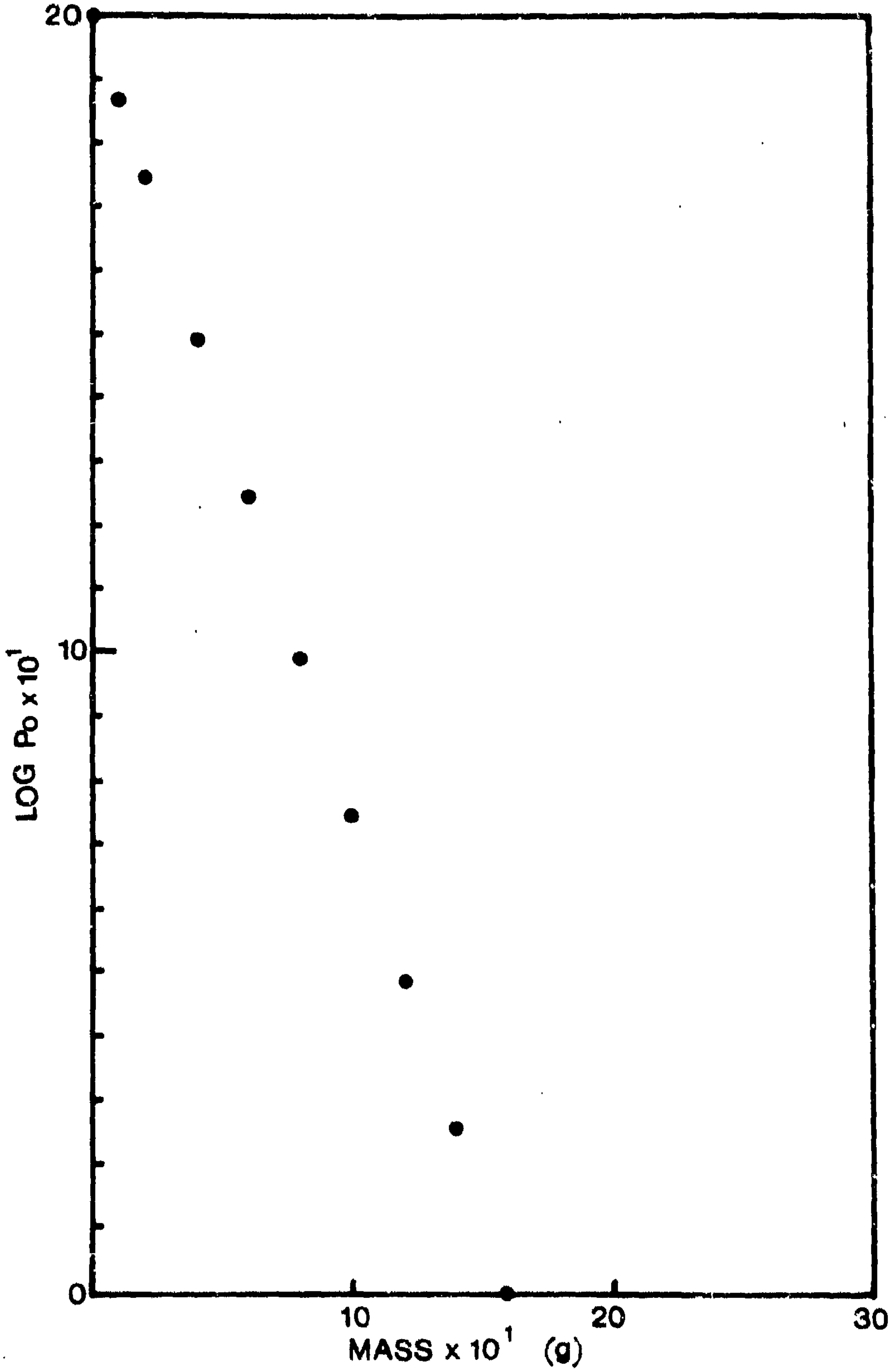

FIG. 1 - PAYMAN DISTRIBUTION O - CONTROL.

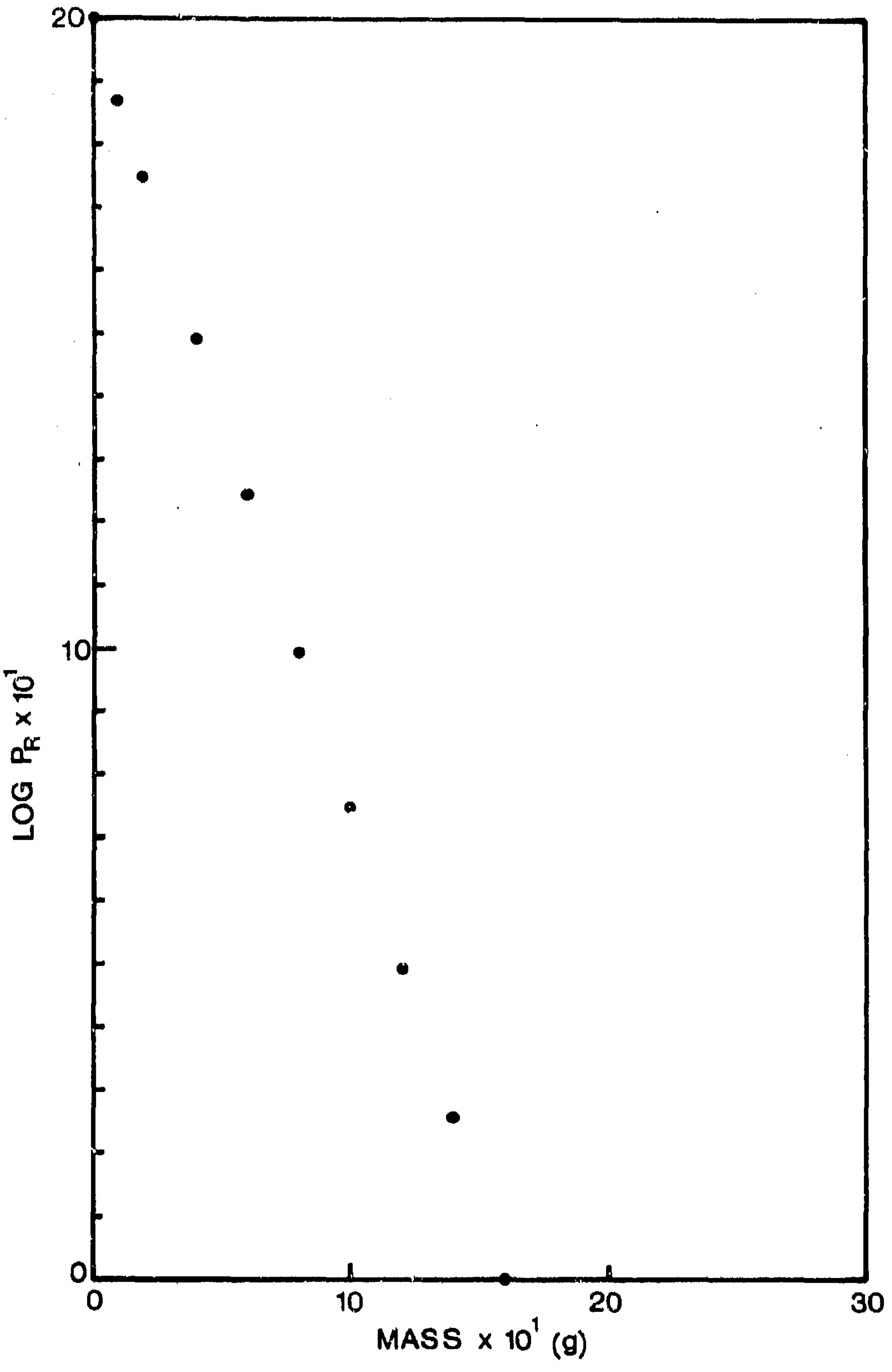

FIG. 2 - PAYMAN DISTRIBUTION R - CONTROL.

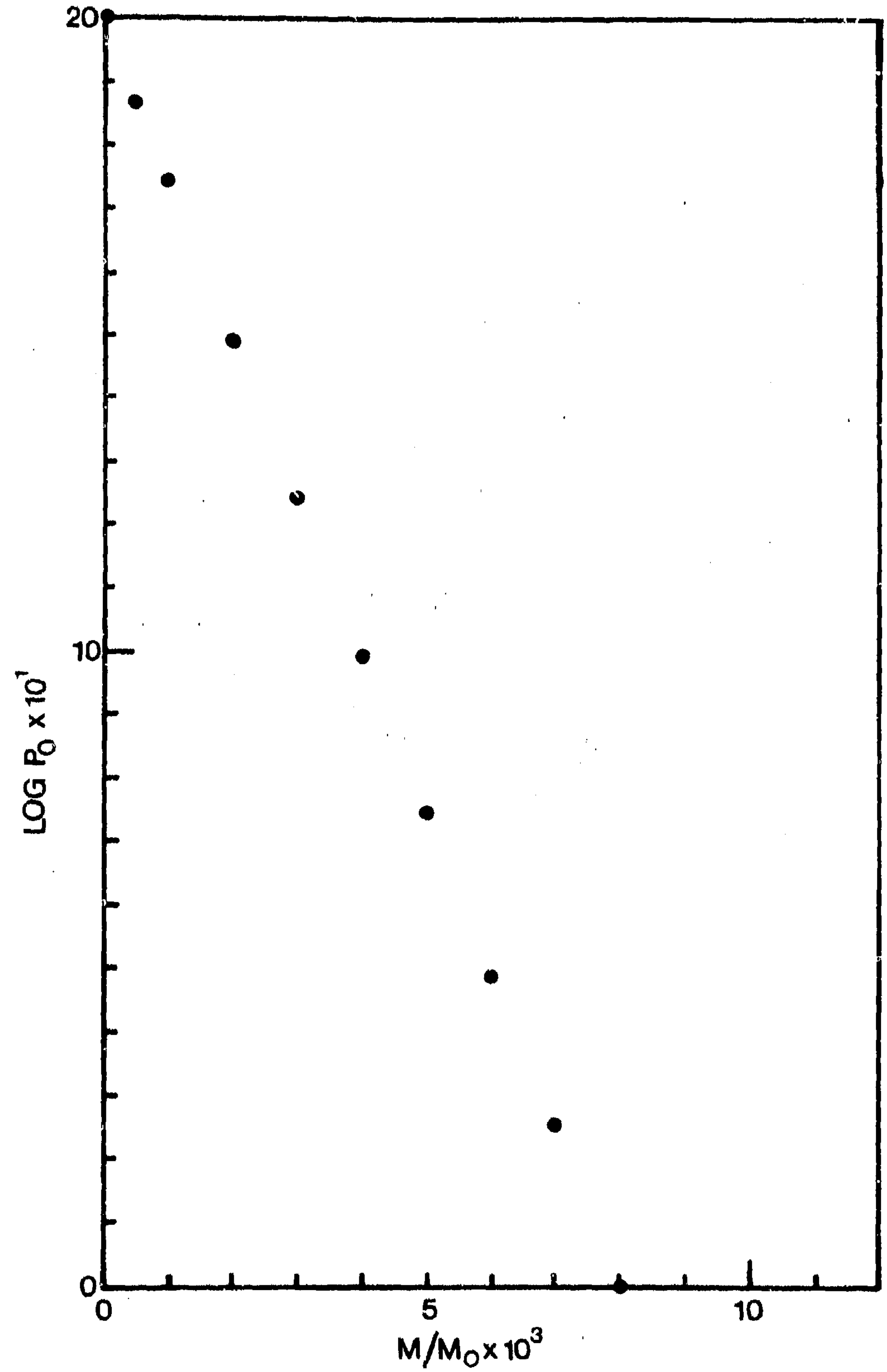

 FIG. 3 - MODIFIED PAYMAN DISTRIBUTION O - CONTROL.

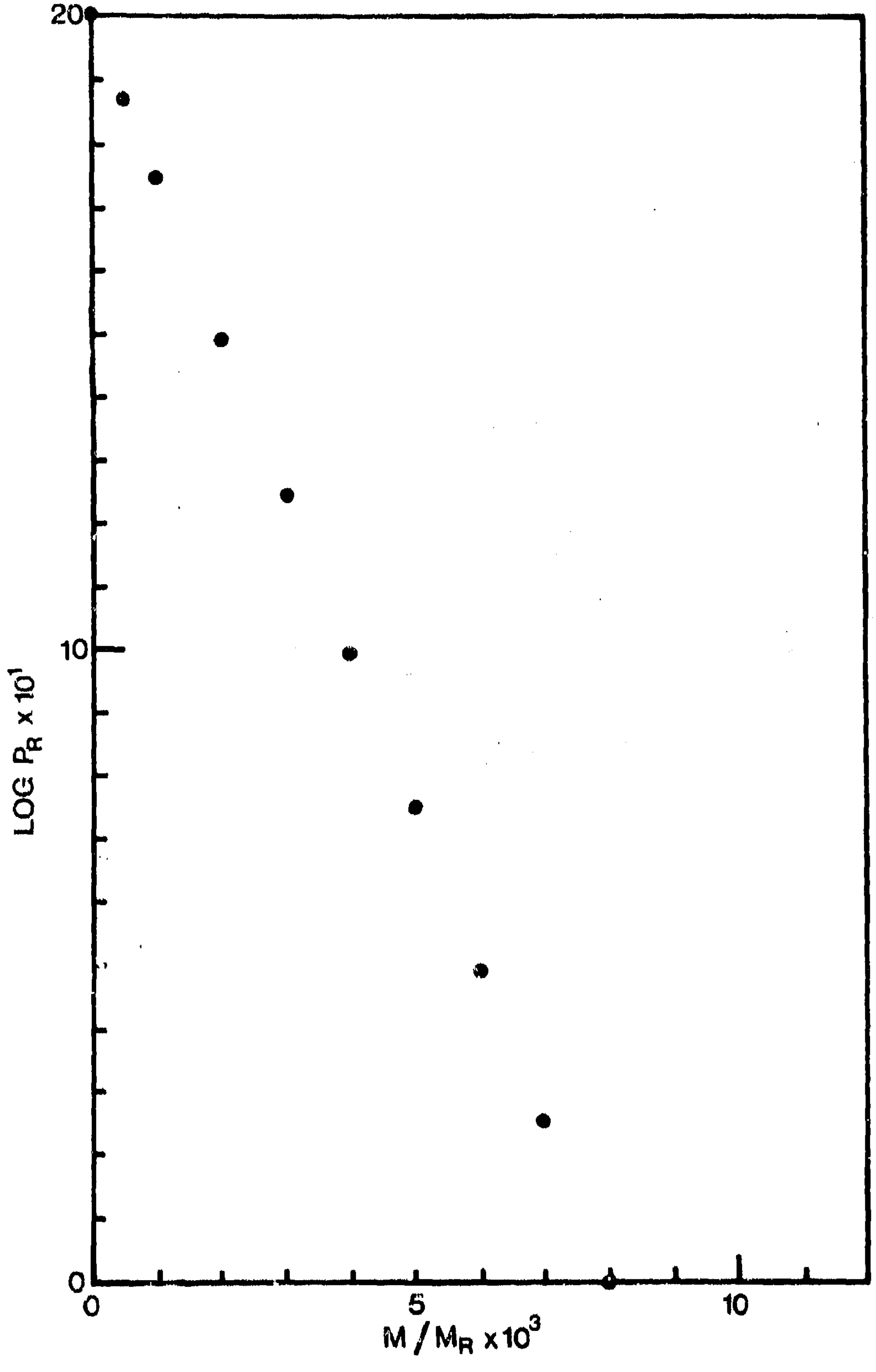

FIG. 4 - MODIFIED PAYMAN DISTRIBUTION R - CONTROL.

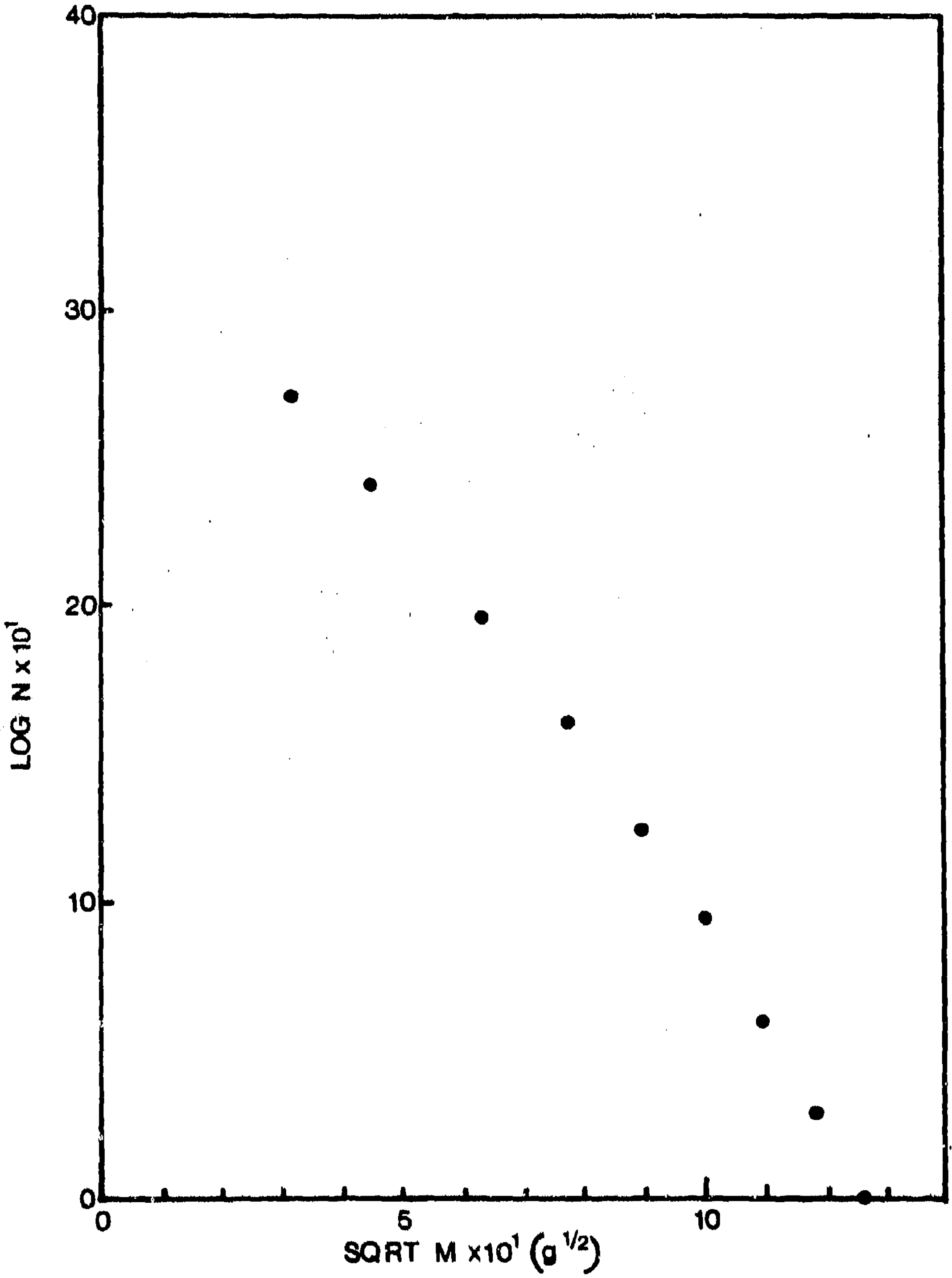

FIG. 5 - MOTT DISTRIBUTION - CONTROL.

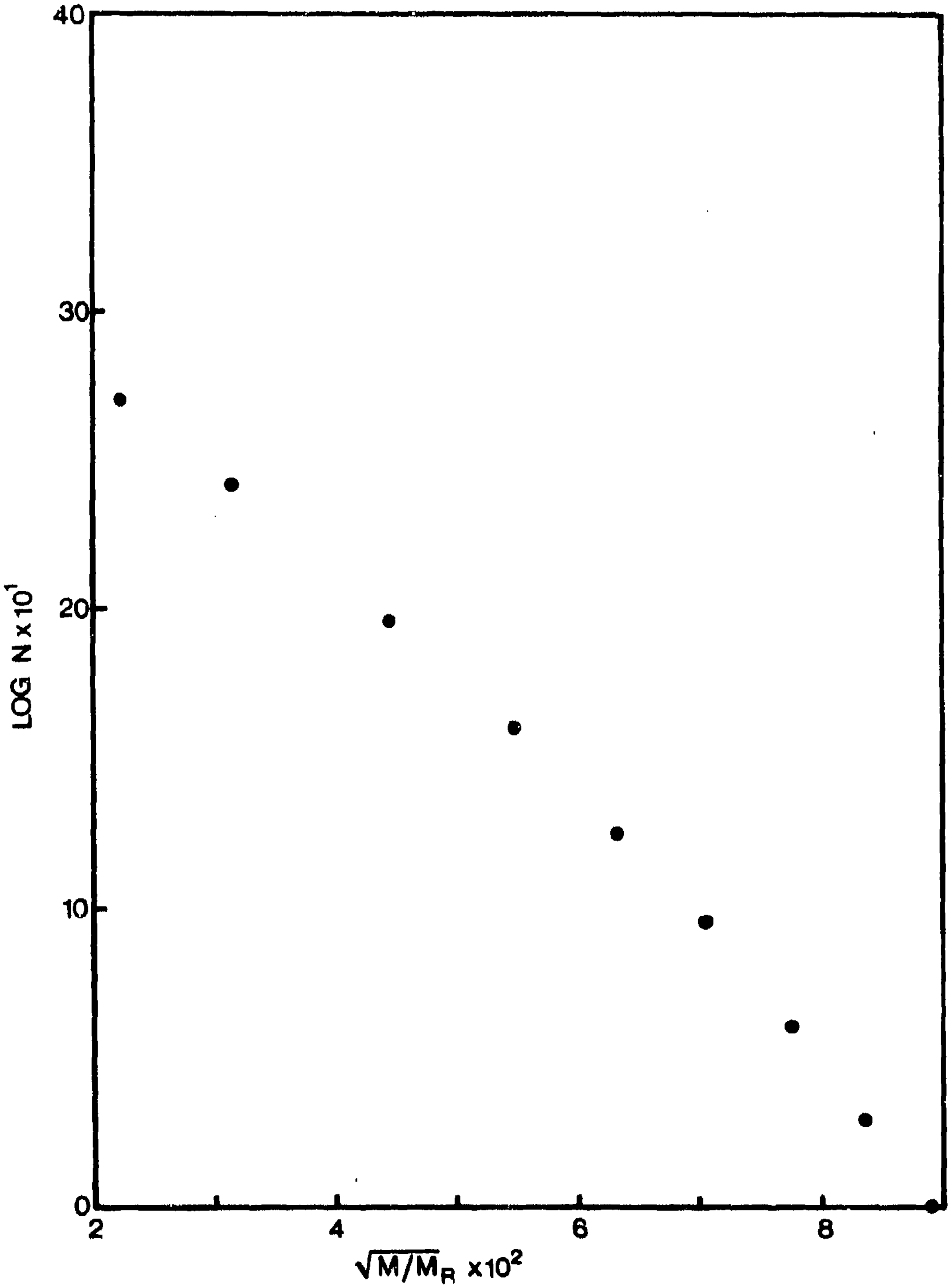

FIG. 6 - MODIFIED MOTT DISTRIBUTION R - CONTROL.

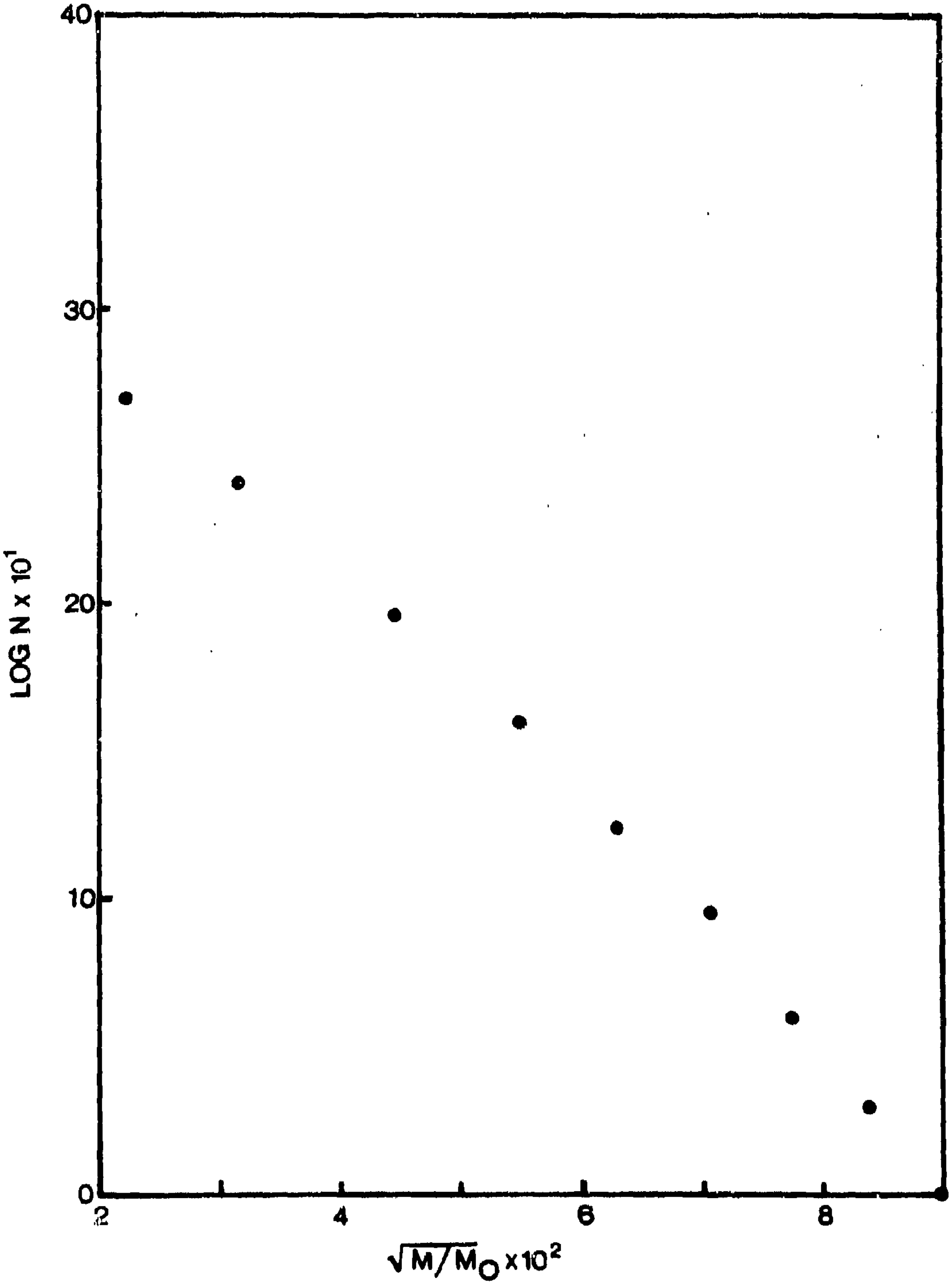

FIG. 7 - MODIFIED MOTT ' .STRIBUTION O - CONTROL.

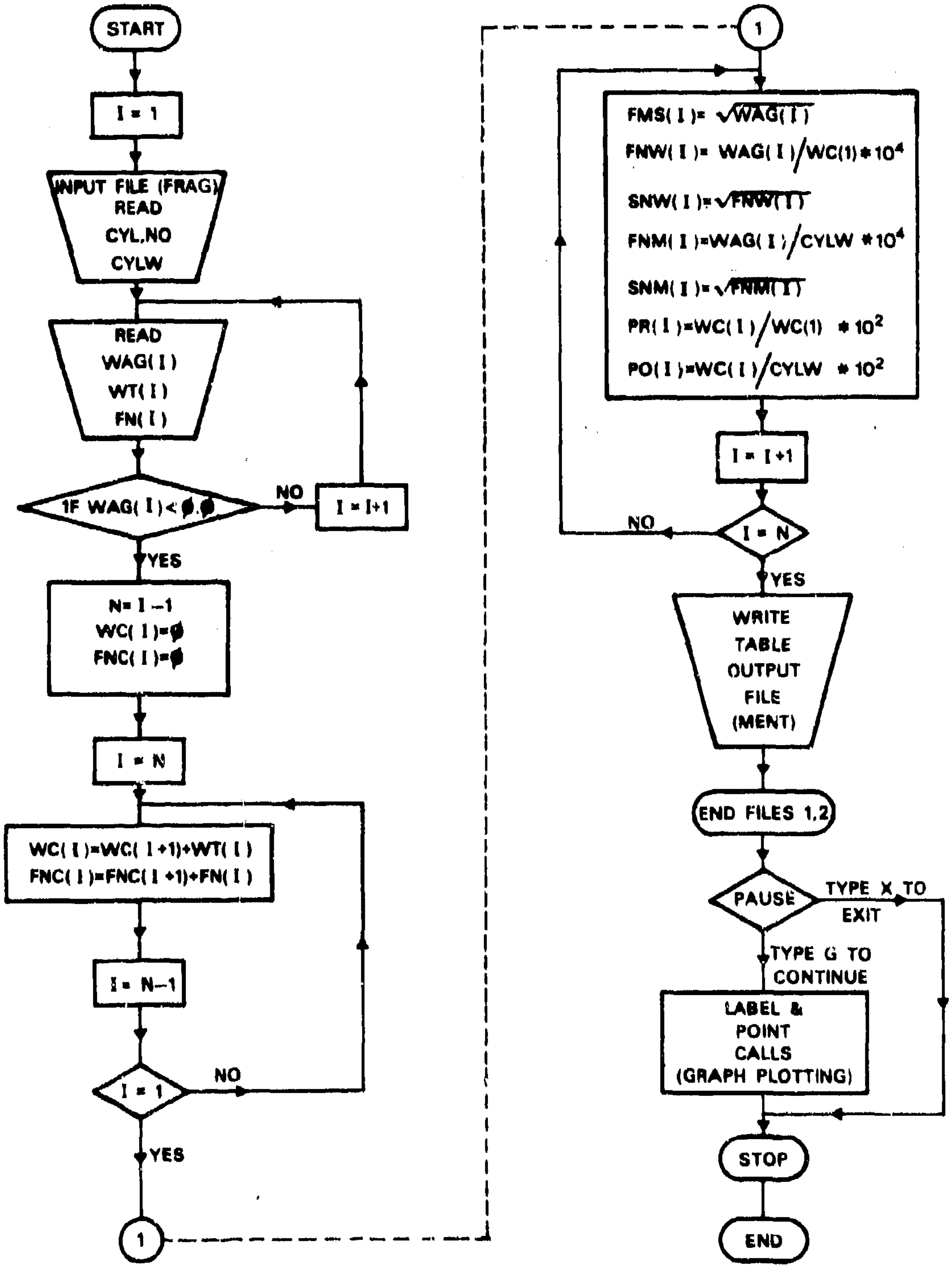

FIG. 8 - BLOCK DIAGRAM OF THE PROGRAM FRAMD.

FIG. 9 - FORTRAN IV VERSION OF PROGRAM FRAMD FOR PRODUCING FRAGMENT MASS AND NUMBER DISTRIBUTIONS.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                           C
C              AMMUNITION METALLURGY GROUP                  C
C                                                           C
C                         FRAMD                             C
C     PROGRAMME FOR CALCULATING FRAGMENT MASS DISTRIBUTION  C
C                                                           C
C     INPUT FILE                               FRAG         C
C          CYL NO                               2A5         C
C          CYL WT                               F6.0        C
C          MASS RANGE,WT,NO (TO 19 LINES) 3F6.0             C
C       ***FRAGMENT NUMBER IS OPTIONAL***                   C
C       ***TERMINATE DATA WITH A NEGATIVE NUMBER***         C
C     OUTPUT FILE TABULATED DATA               MENT         C
C     OUTPUT FILE PLOTTED DATA                 PAYO         C
C          THIS IS SELECTED BY TYPING G TO CONTINUE AND TYPING C
C          A FOR AUTO OR S FOR STANDARD WHEN ASKED FOR LIMITS  C
C          ON AXES                                          C
C                                                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      DIMENSION A(20),B(20),C(20),D(20),F(20),G(20),H(20),P(20),R(20),
     1S(20),WAG(20),WT(20),FN(20),FNC(20),WC(20),FMS(20),FNW(20),
     2SNW(20),FNM(20),SNM(20),PR(20),PO(20),NN(20),NC(20),FOW(20),
     3FOM(20),SOM(20),SOW(20)
      CALL IFILE(1,5HFRAG$)
      CALL OFILE(2,5HMENT$)
    1 FORMAT(2A5)
    2 FORMAT(F6.0)
    3 FORMAT(3F6.0)
    4 FORMAT(////////)
    5 FORMAT(24X,'FRAGMENT MASS DISTRIBUTION'//28X,'CYLINDER # ',
     12A5,/28X,'CYLINDER WT ',F6.1,/)
    6 FORMAT(' MASS   WT   NO  CUMWT CUMNO   PR    PO   SQRT  M/MR
     1  M/MO  SQRT  SQRT'/43X,'MASS  *1E4  *1E4  M/MR  M/MO'/61X,
     2'*1E2  *1E2'/)
    7 FORMAT(F6.2,F6.1,I5,F6.1,I6,2F6.1,F6.2,2F6.1,2F6.2,/)
    8 FORMAT(12X,'MASS  WEIGHT   CUMWT     PR      PO      M/MR
     1    M/MO'/52X,'*1E4    *1E4'/)
    9 FORMAT(9X,F7.2,6F8.1,/)
   11 FORMAT(' LIMITS ON AXES'/' TYPE A FOR AUTO S FOR STANDARD'/)
   12 FORMAT(A5)
      I=1
      READ(1,1)CYL,NO
   10 READ(1,2)CYLW
   20 READ(1,3)WAG(I),WT(I),FN(I)
      IF(WAG(I).LT.0.0)GO TO 30
      I=I+1
      GO TO 20
   30 N=I-1
      WC(I)=0
      FNC(I)=0
      DO40I=N,1,-1
      WC(I)=WC(I+1)+WT(I)
   40 FNC(I)=FNC(I+1)+FN(I)
      DO50I=1,N
      FMS(I)=SQRT(WAG(I))
      FNW(I)=WAG(I)/WC(I)
      SNW(I)=SQRT(FNW(I))
```

(CONTINUED NEXT PAGE)

```
      FNM(I)=WAG(I)/CYLW
      SNM(I)=SQRT(FNM(I))
      PR(I)=(WC(I)/WC(1))*100
      PO(I)=(WC(I)/CYLW)*100
      NN(I)=FN(I)
      NC(I)=FNC(I)
      FOW(I)=FNW(I)*10000
      FOM(I)=FNM(I)*10000
      SOW(I)=SNW(I)*100
   50 SOM(I)=SNM(I)*100
      WRITE(2,4)
      WRITE(2,5)CYL,NO,CYLW
      IF(FNC(1).LT.1.0)GO TO 70
      WRITE(2,6)
      DO60I=1,N
   60 WRITE(2,7)WAG(I),WT(I),NN(I),WC(I),NC(I),PR(I),PO(I),FMS(I),
     1FOW(I),FOM(I),SOW(I),SOM(I)
      GO TO 90
   70 WRITE(2,8)
      DO80I=1,N
   80 WRITE(2,9)WAG(I),WT(I),WC(I),PR(I),PO(I),FOW(I),FOM(I)
   90 WRITE(2,4)
      END FILE 1
      END FILE 2
      PAUSE
      CALL OFILE(1,5HPAYO$)
      TYPE 11
      ACCEPT 12,AQ
      IF(AQ.EQ.'A')GO TO 91
      DATA AX,AY,BX,BY,CX,CY,DX,DY,PK/5.0,2.0,.020,2.0,2.0,4.0,
     10.10,4.0,-1.0/
      GO TO 207
   91 PK=1.0
      IF(WAG(N).LE.0.5)GO TO 100
      IF(WAG(N).LE.1.0)GO TO 101
      IF(WAG(N).LE.2.0)GO TO 102
      IF(WAG(N).LE.5.0)GO TO 103
      IF(WAG(N).LE.10.0)GO TO 104
      GO TO 105
  100 AX=0.50
      GO TO 106
  101 AX=1.0
      GO TO 106
  102 AX=2.0
      GO TO 106
  103 AX=5.0
      GO TO 106
  104 AX=10.0
      GO TO 106
  105 AX=20.0
  106 AY=2.0
      IF(FOW(N).LE.10.0)GO TO 200
      IF(FOW(N).LE.20.0)GO TO 201
      IF(FOW(N).LE.50.0)GO TO 202
      IF(FOW(N).LE.100.0)GO TO 203
      IF(FOW(N).LE.200.0)GO TO 204
      GO TO 205
  200 BX=0.0010
      GO TO 206
  201 BX=0.0020
```

(CONTINUED NEXT PAGE)

```
      GO TO 206
  202 BX=0.0050
      GO TO 206
  203 BX=0.010
      GO TO 206
  204 BX=0.020
      GO TO 206
  205 BX=0.050
  206 BY=2.0
  207 XMIN=0.0
      YMIN=0.0
      XMAX=AX
      YMAX=AY
      DO300I=1,N
      A(I)=WAG(I)
  300 B(I)=ALOG10(PO(I))
      CALL PLOT(1,0.0,-5.0,2)
      CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'MASS ','LOGPO','PAYMAN DISTRIBUT
     1ION O     ',5)
      DO301I=1,N
  301 CALL POINT(1,A(I),B(I),3,1)
      DO400I=1,N
  400 C(I)=ALOG10(PR(I))
      CALL PLOT(1,XMIN,YMIN,3)
      XMIN=0.
      YMIN=0.
      CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'MASS ','LOGPR','PAYMAN DISTRIBUT
     1ION R     ',5)
      DO401I=1,N
  401 CALL POINT(1,A(I),C(I),3,1)
      XMAX=BX
      YMAX=BY
      DO500I=1,N
  500 D(I)=FNM(I)
      CALL PLOT(1,XMIN,YMIN,3)
      XMIN=0.
      YMIN=0.
      CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'M/MO ','LOGPO','MODIFIED PAYMAN
     1 DISTRIBUTION O ',6)
      DO501I=1,N
  501 CALL POINT(1,D(I),B(I),3,1)
      DO600I=1,N
  600 F(I)=FNW(I)
      CALL PLOT(1,XMIN,YMIN,3)
      XMIN=0.
      YMIN=0.
      CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'M/MR ','LOGPR','MODIFIED PAYMAN
     1 DISTRIBUTION R ',6)
      DO601I=1,N
  601 CALL POINT(1,F(I),C(I),3,1)
      IF(FNC(1).LT.1.0)GO TO 1100
      IF(PK.LT.0.0)GO TO 705
      IF(FMS(N).LE.0.5)GO TO 602
      IF(FMS(N).LE.1.0)GO TO 603
      IF(FMS(N).LE.2.0)GO TO 604
      GO TO 605
  602 CX=0.5
      GO TO 606
  603 CX=1.0
      GO TO 606
```

(CONTINUED NEXT PAGE)

```
 604 CX=2.0
     GO TO 606
 605 CX=5.0
 606 CY=4.0
     IF(SOW(N).LE.2.0)GO TO 700
     IF(SOW(N).LE.5.0)GO TO 701
     IF(SOW(N).LE.10.0)GO TO 702
     GO TO 703
 700 DX=0.020
     GO TO 704
 701 DX=0.050
     GO TO 704
 702 DX=0.10
     GO TO 704
 703 DX=0.20
 704 DY=4.0
 705 XMAX=CX
     YMAX=CY
     DO800I=1,N
     H(I)=FMS(I)
     SNC=NC(I)
 800 P(I)=ALOG10(SNC)
     CALL PLOT(1,XMIN,YMIN,3)
     XMIN=0.
     YMIN=0.
     CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'SQRTM','LOGN ','MOTT DISTRIBUTIO
    1N    ',4)
     DO801I=1,N
 801 CALL POINT(1,H(I),P(I),3,1)
     XMAX=DX
     YMAX=DY
     DO900I=1,N
 900 R(I)=SNW(I)
     CALL PLOT(1,XMIN,YMIN,3)
     XMIN=0.
     YMIN=0.
     CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'RM/MR','LOGN ','MODIFIED MOTT
    1DISTRIBUTION R    ',6)
     DO901I=1,N
 901 CALL POINT(1,R(I),P(I),3,1)
     DO1000I=1,N
1000 S(I)=SNM(I)
     CALL PLOT(1,XMIN,YMIN,3)
     XMIN=0.
     YMIN=0.
     CALL LABEL(1,XMIN,YMIN,XMAX,YMAX,'RM/MO','LOGN ','MODIFIED MOTT
    1 DISTRIBUTION O    ',6)
     DO1001I=1,N
1001 CALL POINT(1,S(I),P(I),3,1)
1100 STOP
     END
```

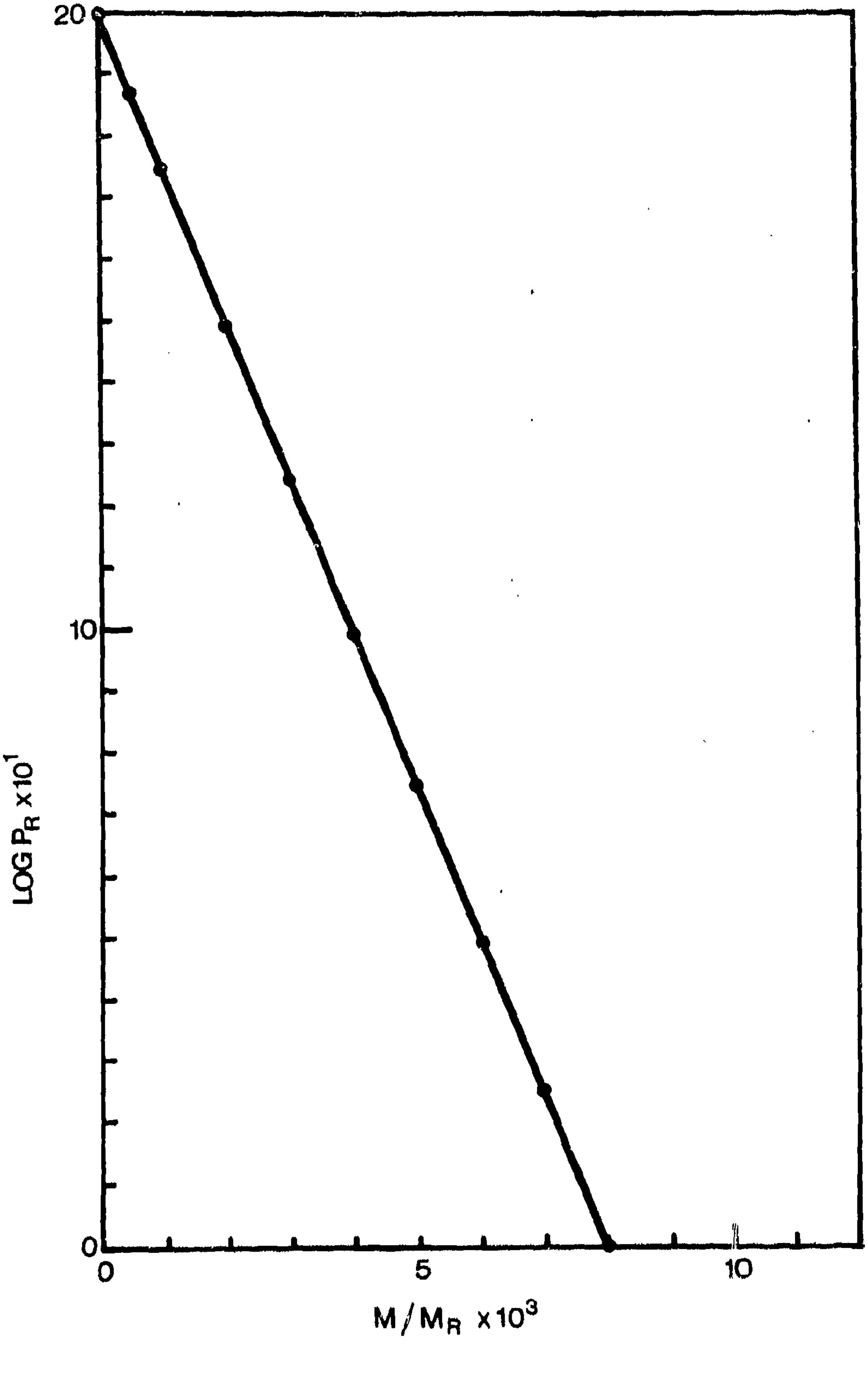

 FIG. 10 - MODIFIED PAYMAN DISTRIBUTION R - CONTROL.

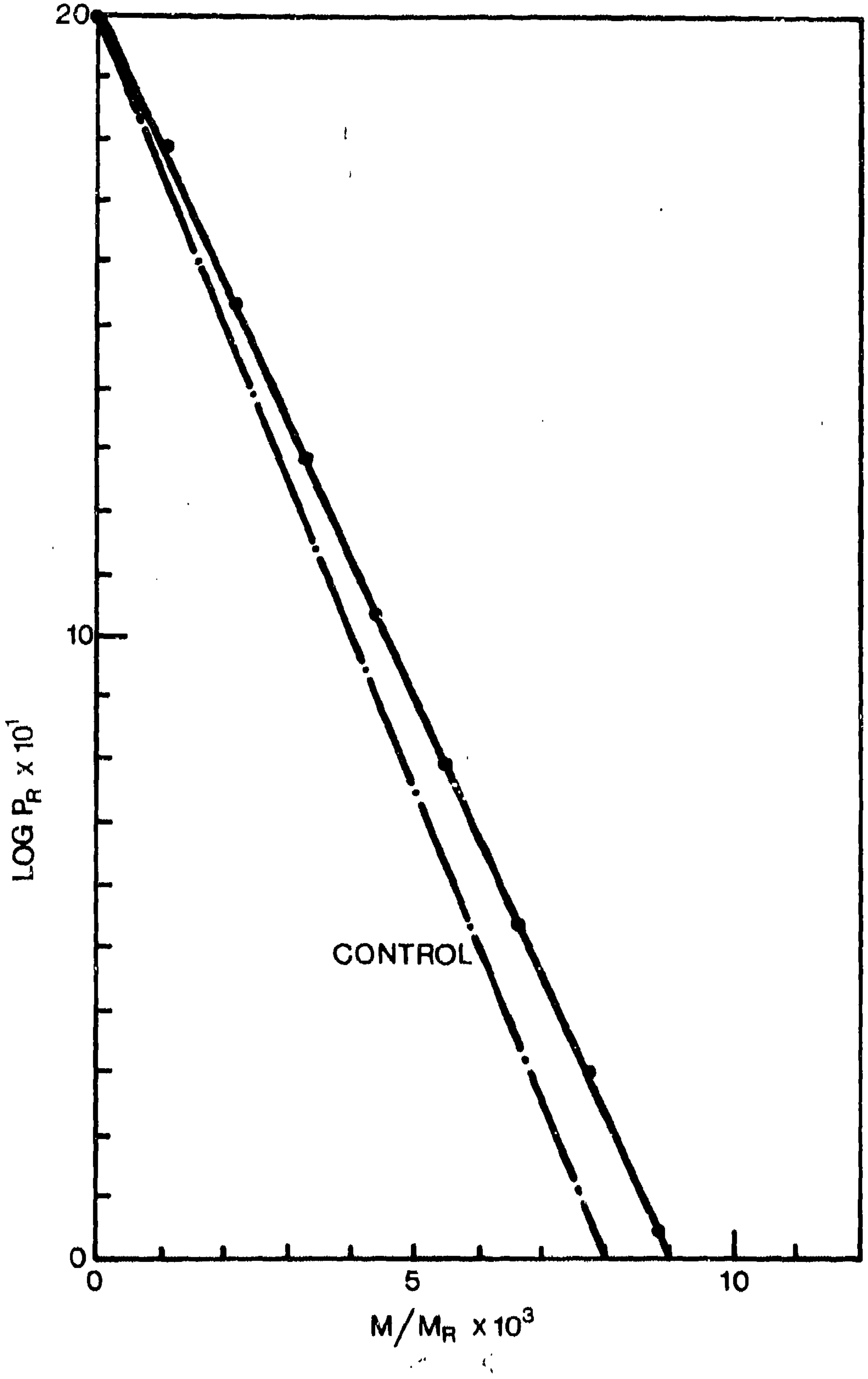

FIG. 11 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 1.

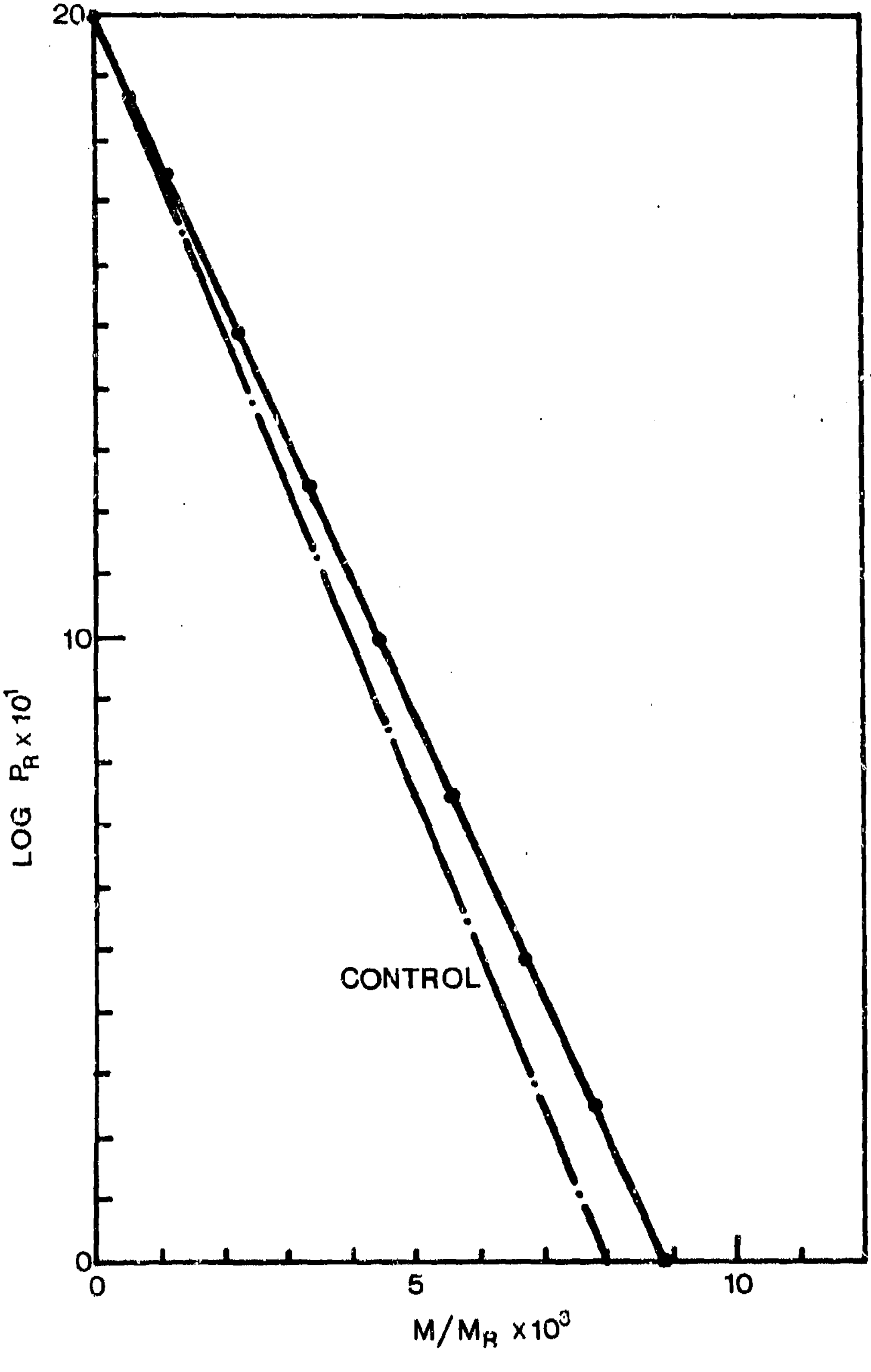

FIG. 12 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 2.

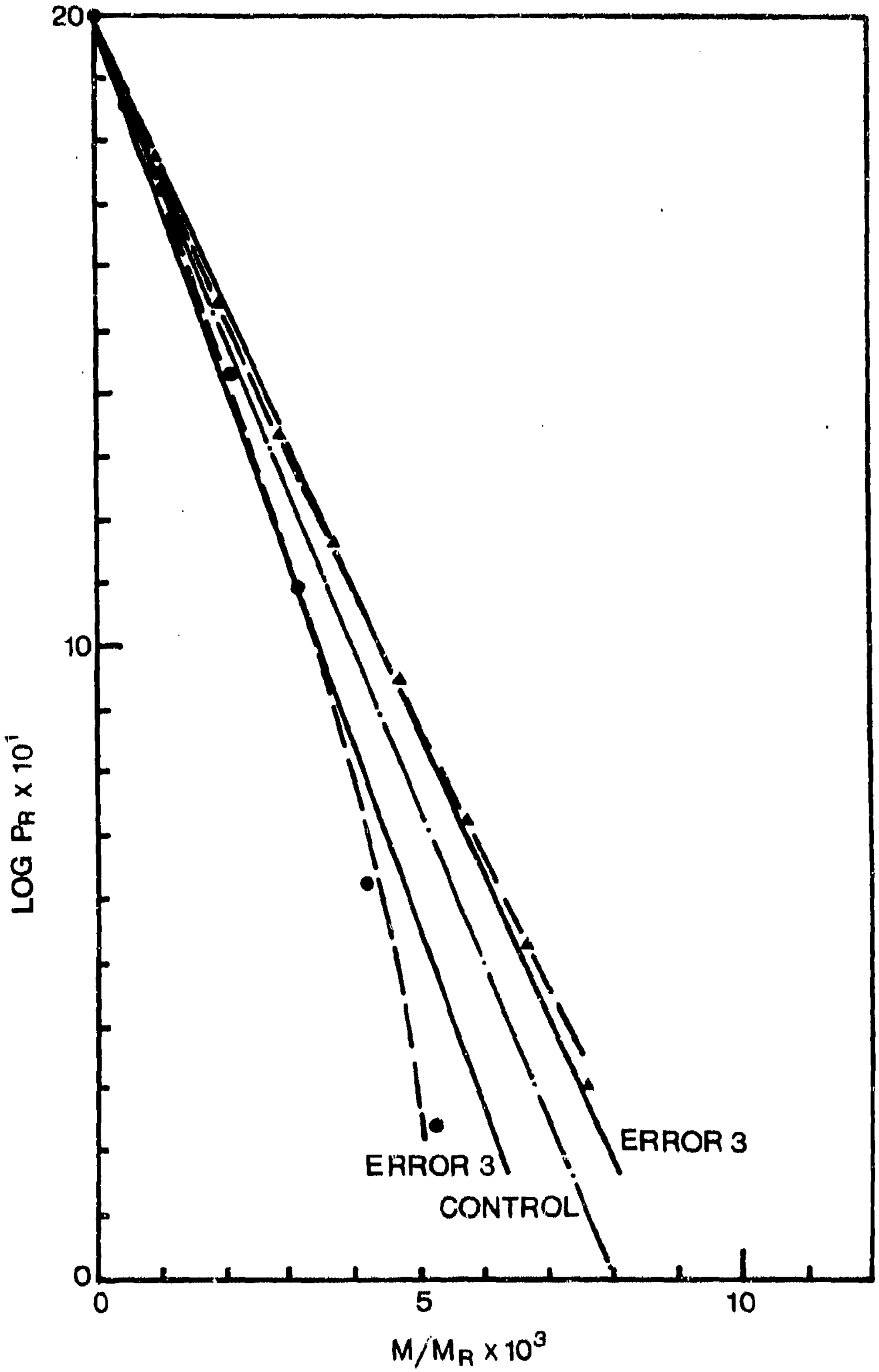

FIG. 13 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 3.

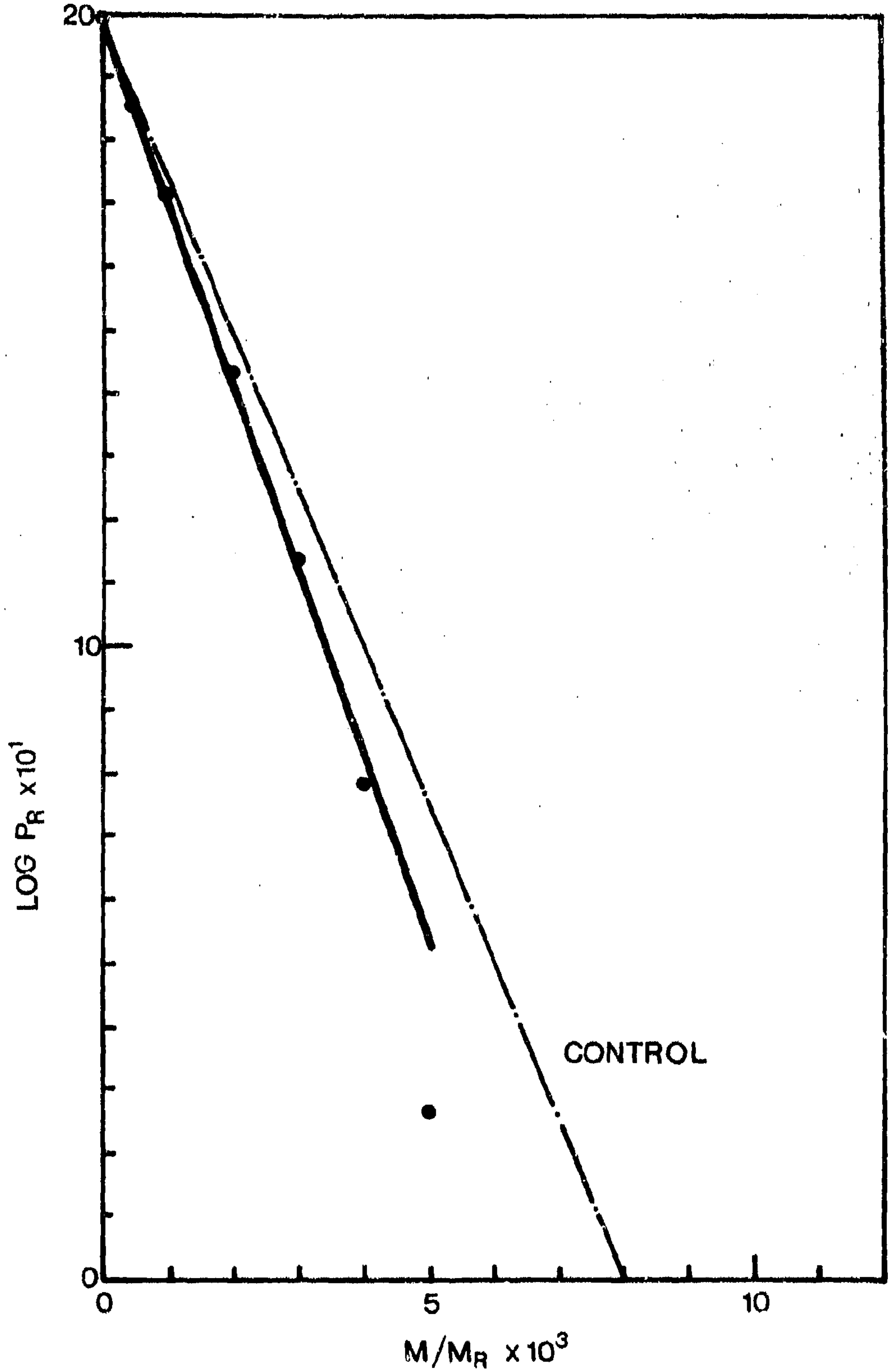

FIG. 14 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 4.

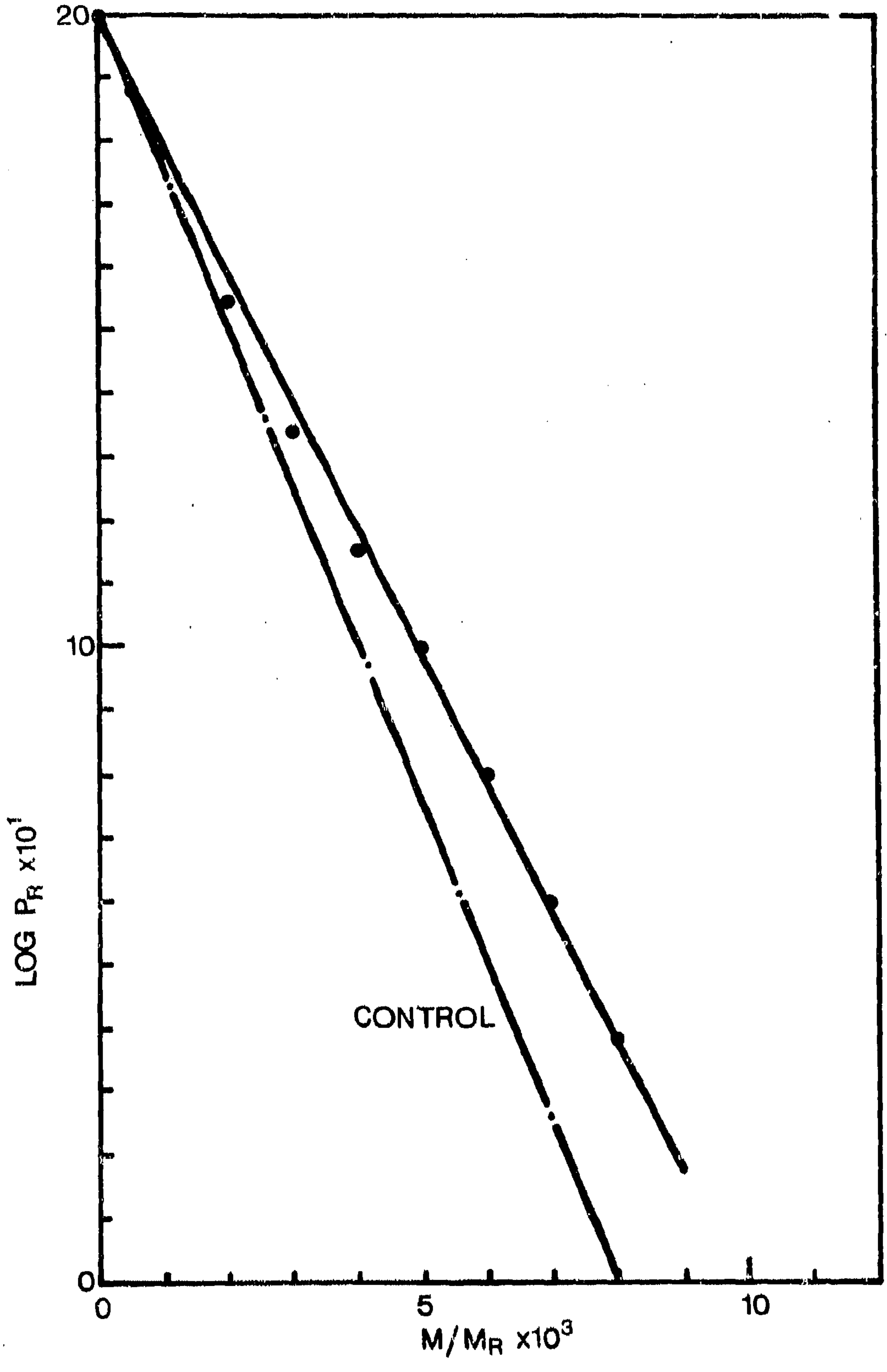

FIG. 15 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 5.

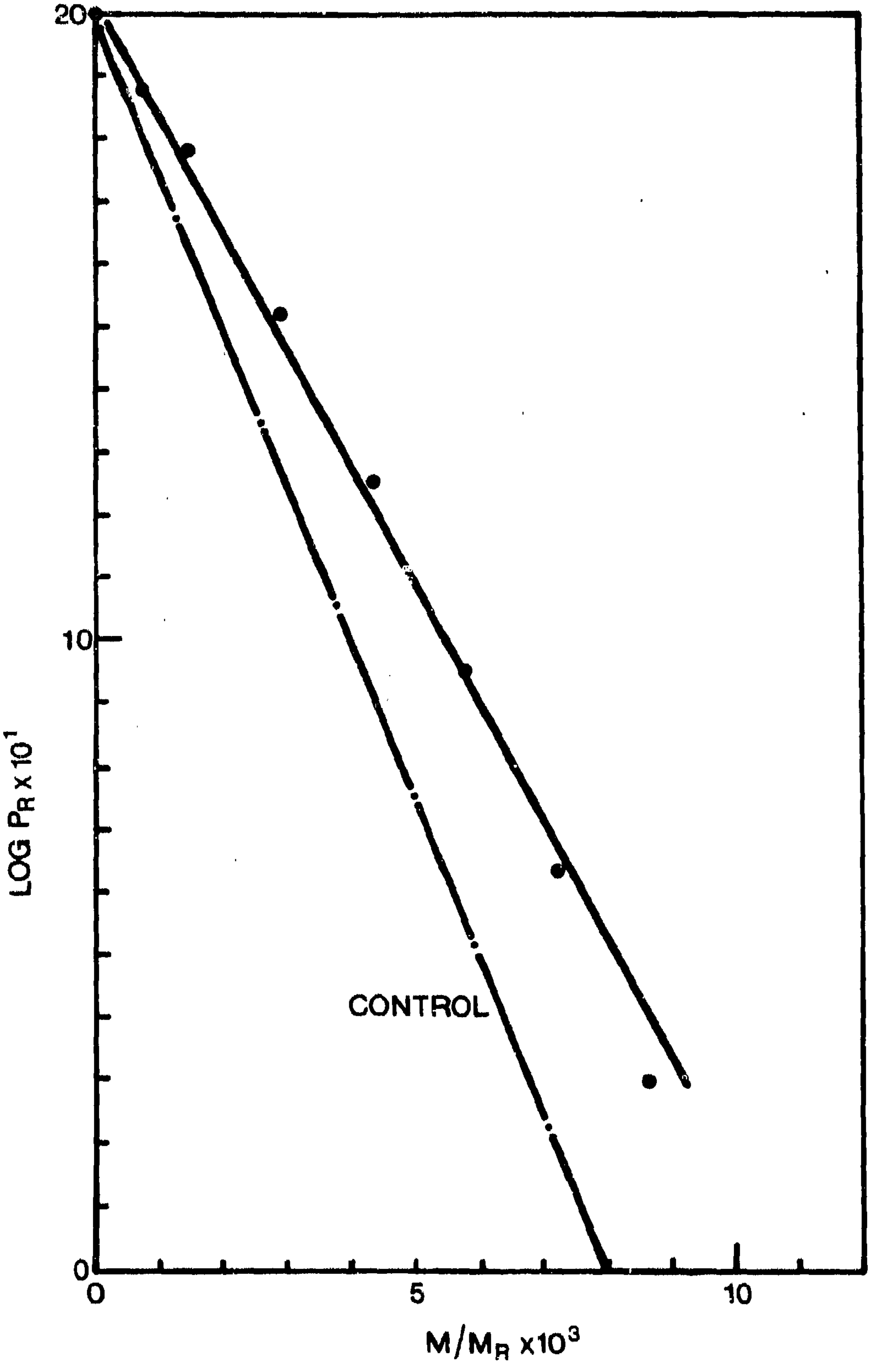

 FIG. 16 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 6.

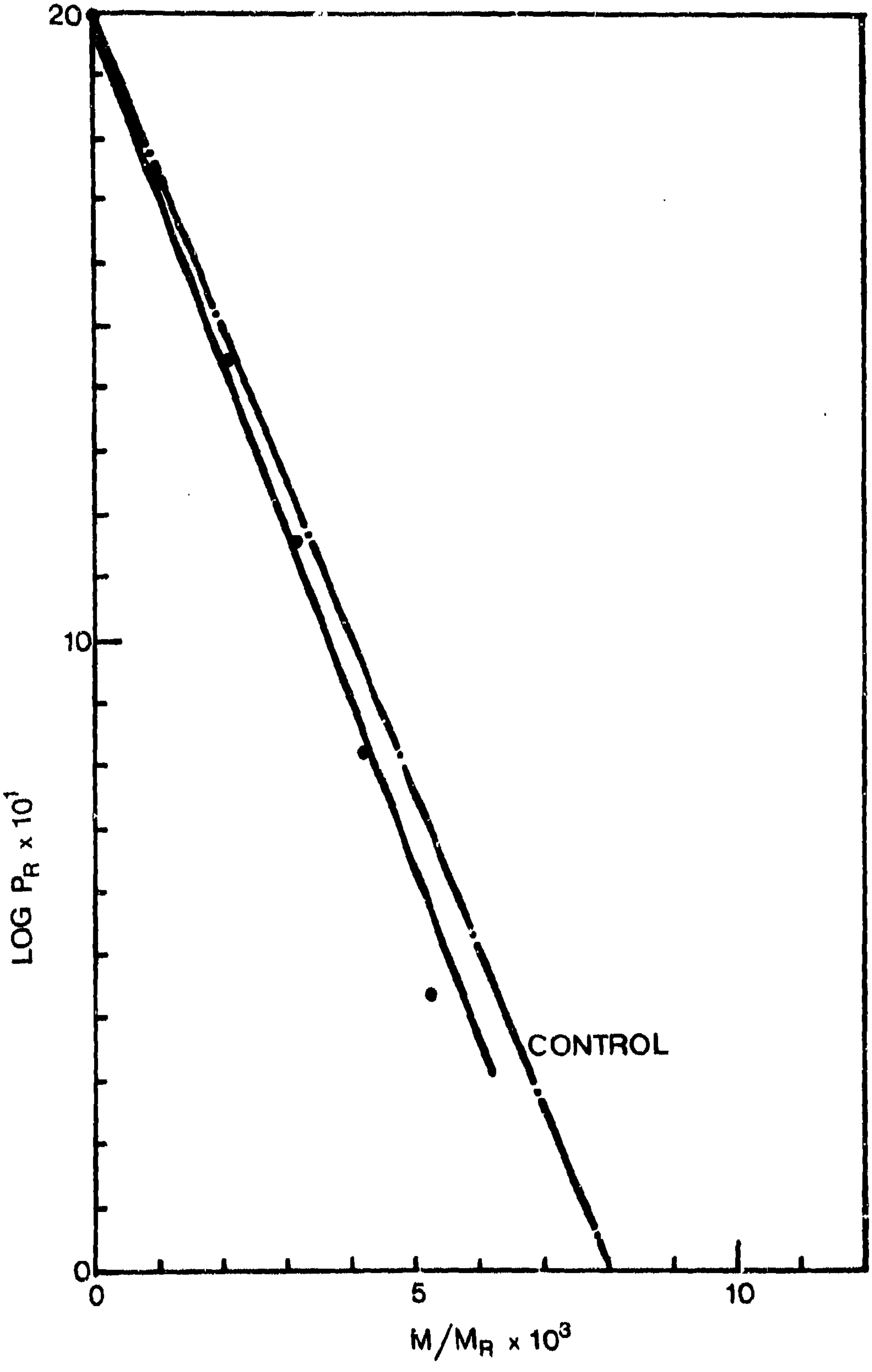

FIG. 17 - MODIFIED PAYMAN DISTRIBUTION R - ERROR 7.

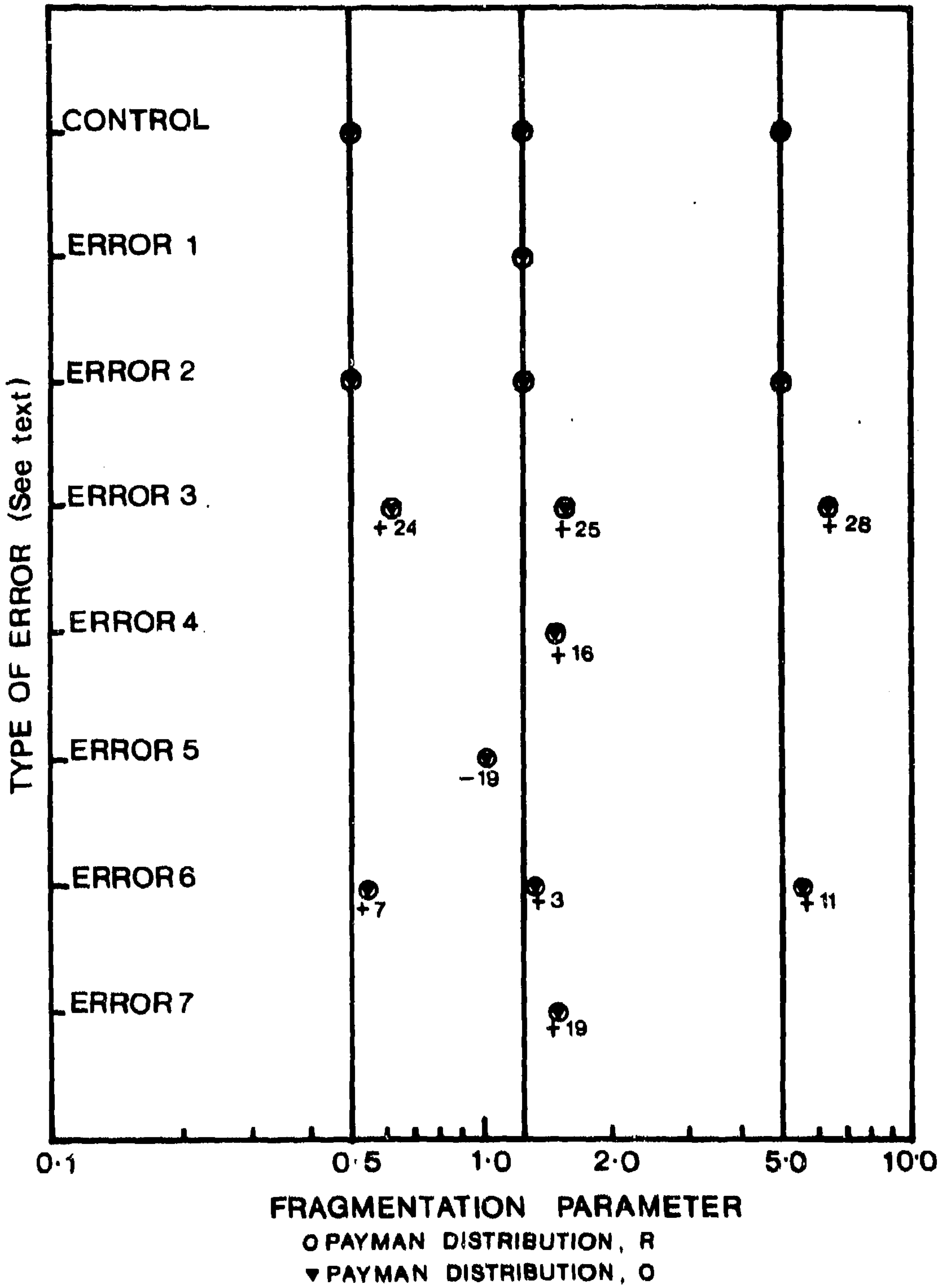

FIG. 18 - SUMMARY OF RESULTS FOR PAYMAN R AND PAYMAN O DISTRIBUTIONS. NUMBERS SHOWN ARE THE PER CENT DEVIATION FROM CONTROL.

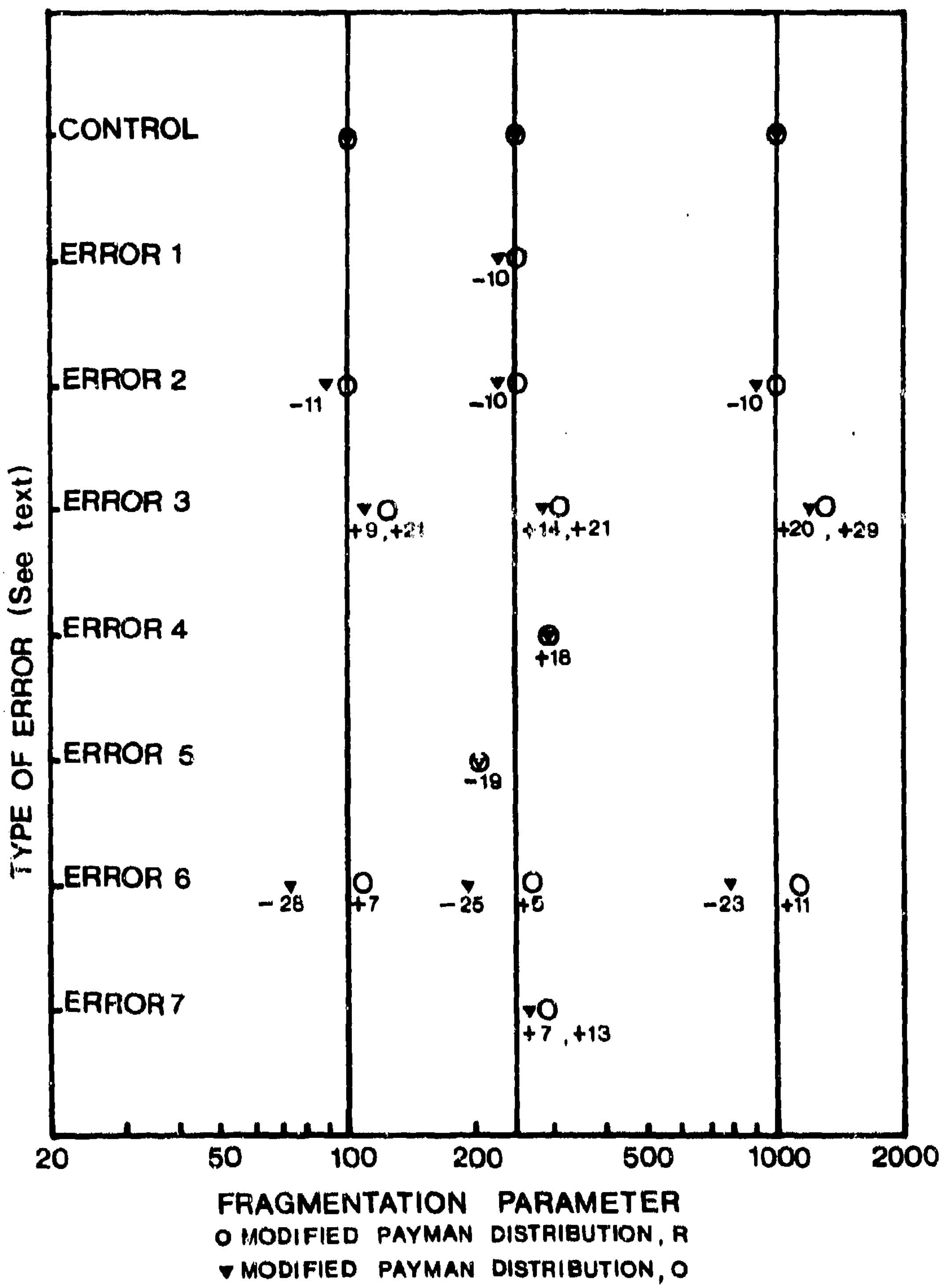

FIG. 19 - SUMMARY OF RESULTS FOR MODIFIED PAYMAN R AND MODIFIED PAYMAN O DISTRIBUTIONS. NUMBERS SHOWN ARE THE PER CENT DEVIATION FROM THE CONTROL VALUE IN EACH CASE.

(MRL REPORT 549)

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